PB86-164084

Large Soil Absorption Systems for Wastewaters from Multiple-Home Developments

RSE, Inc., Madison, WI

Prepared for

Environmental Protection Agency, Cincinnati, OH

Feb 86

U.S. Department of Commerce
National Technical Information Service
NTIS.

PB86-164084

EPA/600/2-86/023
February 1986

LARGE SOIL ABSORPTION SYSTEMS FOR WASTEWATERS FROM MULTIPLE-HOME DEVELOPMENTS

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/2-86/023	2.	3. RECIPIENT'S ACCESSION NO. PB86 164084/AS
4. TITLE AND SUBTITLE Large Soil Absorption Systems for Wastewaters from Multiple-Home Developments		5. REPORT DATE February 1986
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Siegrist, Robert L., Anderson, Damann L., and Hargett, David L.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS RSE Group Scientists/Engineers 2445 Darwin Road Madison, WI 53704		10. PROGRAM ELEMENT NO. AZB1B
		11. CONTRACT/GRANT NO. 68-03-3057
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory--Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Final (1980-1983)
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

An investigation was conducted to provide insight into the design and performance of large soil absorption systems for treatment and disposal of wastewaters from multiple-home developments. The objectives were to investigate absorption system performance and identify potential deficiencies in presently used design criteria. Where possible, recommendations regarding more appropriate design and operation practices were to be made.

The study was conducted in three parts. A survey of state regulatory agencies was conducted to enable characterization of the distribution, regulatory structures, design restrictions and state attitudes associated with multiple-home systems. An in-depth field investigation of the community wastewater absorption system at Westboro, Wisconsin was conducted between June 1981 and May 1983. This work included delineation of the soil and site characteristics and monitoring of the applied wastewater, abosrption system soil infiltrability, subsystem soil moisture and pore gas, and groundwater impacts. The final part of this study included a more casual field investigation of six multiple home systems located in the State of Washington. The basic characteristics of each system were determined including the facility design, soil conditions, applied wastewater character and the absorption system performance.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 104
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

DISCLAIMER

The information in this document has been funded wholly by the United States Environmental Protection Agency under Contract No. 68-03-3057 with Urban Systems Research and Engineering, Inc., and the RSE Group. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This study of large soil absorption systems for domestic wastewater treatment and disposal revealed that their design is not based on entirely rational criteria at this time. Although many design criteria have not yet been addressed this report emphasizes the need to greatly improve site evaluation procedures to more thoroughly characterize the potential movement of effluent with the groundwater, predict mounding and maximize the available landscape. Several design improvements noted include the use of trenches wherever possible in lieu of beds, resting cycles with multiple cells and shallow trench use wherever feasible.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

Large subsurface soil absorption systems are being promoted as low-cost, effective alternatives for treatment and disposal of wastewaters from subdivisions, small communities and similar applications. When a large system was constructed for the community of Westboro, Wisconsin in 1977, it was one of the first of its kind in the country. Since that time, however, many similar systems are in design, under construction or in operation.

The design and operation practices applied and the performance expected from large systems have largely evolved from experience gained with small, single-home systems. However, lacking field experience regarding the performance of community-scale systems, the suitability of this practice remains in question.

An investigation was conducted to provide insight into the design and performance of large soil absorption systems for treatment and disposal of wastewaters from multiple-home developments. The objectives were to investigate absorption system performance and identify potential deficiencies in presently used design criteria. Where possible, recommendations regarding more appropriate design and operation practices were to be made.

The study was conducted in three parts. A survey of state regulatory agencies was conducted to enable characterization of the distribution, regulatory structures, design restrictions and state attitudes associated with multiple-home systems. An in-depth field investigation of the community wastewater absorption system at Westboro, Wisconsin was conducted between June 1981 and May 1983. This work included delineation of the soil and site characteristics and monitoring of the applied wastewater, absorption system soil infiltrability, subsystem soil moisture and pore gas, and groundwater impacts. The final part of this study included a more casual field investigation of six multiple home systems located in the State of Washington. The basic characteristics of each system were determined including the facility design, soil conditions, applied wastewater character and the absorption system performance.

This report was submitted in partial fulfillment of Contract No. 68-03-3057 by RSE under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period from 1980 to 1983, and work was completed as of September, 1983.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD$_5$	--5-day biochemical oxygen demand
cc	--cubic centimeter
CL$^-$	--chloride
cm	--centimeter
COD	--chemical oxygen demand
Coli	--coliform organisms
Cond.	--conductivity
d	--day
D.O.	--dissolved oxygen
Fecal Coli.	--fecal coliform
ft	--feet
ft^2	--square feet
gm	--gram
gal.	--gallon
gpd	--gallons per day
gpm	--gallons per minute
h, hr	--hour
H_2O	--water
IC	--infiltration capacity
i.d.	--inside diameter
in	--inch
IR	--infiltration rates
pH	--negative log of the hydrogen ion activity
SD	--Standard Deviation
SCS	--soil conversation service
P	--phosphorus
SMT	--soil moisture tension
t	--time
temp	--temperature
TDS	--total dissolved solids
TKN	--Total Kjeldahl Nitrogen
TS	--total solids
TVS	--total volatile solids
TVSS	--total volatile suspended solids
kg	--Kilogram
L	--liter
lb	--pound
Log	--Logrithm
L/min	--liters per minute
m	--meter
m^2	--square meter
m^3	--cubic meter
max	--maximum
mbar	--millibar
mm	--millimeter
mg	--milligram
mg/L	--milligrams per liter
min	--minute, minimum
mL	--milliliter
TSS	--total suspended solids
USDA	--U.S. Dept. Agriculture
n	--number
N	--Nitrogen
NH_4-N	--Ammonia Nitrogen
NO_3-N	--Nitrate Nitrogen
o.d.	--outside diameter

SYMBOLS

°C	--degrees celsius (centigrade)
K	--hydraulic conductivity
	--micro, micron
#	--number
%	--percentage

SYMBOLS (continued)

R_b	--hydraulic resistance of barrier or crust
Z	--height above datum

ACKNOWLEDGMENTS

The performance of this study was made possible through funding provided by U.S. Environmental Protection Agency, Contract No. 68-03-3057, Study Area #2. The efforts of several other parties also contributed to the completion of this study. Past efforts by staff of the Small Scale Waste Management Project at the University of Wisconsin resulted in much background information on the facilities at Westboro and the establishment of a network of groundwater monitoring wells, all of which were utilized in the present study. Carl C. Crane and Associates of Madison, Wisconsin shared their knowledge of the system design, construction and operation and provided valuable surveying and drafting services. The Town of Westboro allowed the monitoring described in this report to occur and residents were patient with the project staff throughout the study. Finally, the efforts of others not specifically recognized here are gratefully appreciated.

SECTION 1

INTRODUCTION

Large subsurface soil absorption systems for treatment and disposal of wastewaters from subdivisions and small communities are becoming increasingly popular. When the large soil absorption system was constructed for the community of Westboro, Wisconsin in 1977, it was one of the first of its kind in the country. Since that time many similar systems are under design, construction or in operation. These systems are being designed not as interim solutions until conventional sewerage arrives, but as permanent means of wastewater management in previously unsewered areas.

The design and operation practices utilized for large multiple-home soil absorption systems appear to have simply evolved from the laboratory and field experience gained with small, single-home systems. However, lacking field experience regarding the performance of community-scale systems, the suitability of this practice remains in question. As the size of a subsurface soil absorption system increases to handle the wastewater from a small community the design, construction and management practices necessary to ensure acceptable performance become less clear. Figure 1 presents numerous fundamental factors which interact dynamically to influence the performance of large soil absorption systems.

Absorption

- Condition of Infiltrative Surface
    - Compaction/Smearing
    - Gravel Masking
    - Soil Clogging
- Condition of Subsystem
    - Soil Permeability
    - Unsaturated Flow Regime
    - Groundwater Mounding

Purification

- Wastewater Composition
- Loading Pattern
- Soil Characteristics
    - Texture
    - Structure
    - Unsaturated Depth
- Subsystem Aeration Status
- Climate
- System Age

Figure 1. Example Variables Potentially Affecting the Performance of Community Soil Absorption Systems.

The objectives of this study were to investigate the performance of community-scale soil absorption systems, to identify potential deficiencies in presently used design criteria and to develop recommendations regarding design and operation practices. More specifically, the project endeavored to accomplish the following:

1. Determine the current attitudes, policies and level of use of community-scale subsurface wastewater absorption systems.

2. Investigate in detail, the performance characteristics of the community wastewater absorption system in Westboro, Wisconsin, and

3. Characterize, generally, a number of multiple-home wastewater absorption systems in the state of Washington.

This study was accomplished between June 1981 and December 1983. The overall study was coordinated by RSE while each of the study objectives was accomplished through the efforts of staff from several organizations:

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SECTION 2

CONCLUSIONS

The use of large soil absorption systems for subdivisions and small communities has grown in recent years. The level of use varies widely from state to state as do the regulatory structures and policies. In general, siting and design requirements imposed on large systems are not markedly different than those used for small systems. Despite their increased use, regulatory agencies appear to have little sound experience regarding large system performance.

Soil and site characteristics significantly influence the design and performance of Large soil absorption systems. It is inappropriate to use small diameter boreholes and simple percolation tests to assess site suitability and to design wastewater absorption systems. Inspection of stem cuttings from a flight auger or even an undisturbed core from a split spoon sampler may not adequately reveal important soil morphological features. Natural soil percolation rates determined through standard procedures likely reflect horizontal permeabilities and not the vertical permeability of restrictive horizon(s).

Design infiltration rates to yield successful long-term operation of large subsurface wastewater absorption systems are poorly defined. Appropriate rates for various effluent compositions, loading schedules, infiltrative surface geometries and soil conditions have not been delineated as yet.

The contaminant load in domestic septic tank effluent may be too great to enable long-term operation of some large subsurface wastewater absorption systems at the infiltration rates currently prescribed. Higher levels of pretreatment to reduce the levels of oxygen-consuming materials, suspended solids and other constituents may be necessary to sustain high design infiltration rates (e.g. 5 cm/d), and to achieve adequate purification prior to groundwater recharge.

Anaerobic conditions may predominate under large mature soil absorption systems, even those installed in sandy soils. Alternative system types such as narrow, trenches may be necessary to facilitate aerobic soil environments.

The continuous application of large volumes of wastewater to subsurface soils may raise the groundwater surface under such systems in some cases to an extent which significantly reduces the depth of unsaturated soil beneath the system. This could diminish renovation of the applied wastewater, especially in soils with significant capillary fringe above the saturated zone. Analytical models for predicting groundwater mounding beneath soil absorption systems appear difficult to apply and imprecise in their predictions due to the input data required and the heterogenous, anisotropic character of many soil systems.

SECTION 3

RECOMMENDATIONS

The results of this investigation and related work have raised several basic questions regarding appropriate practices for siting, design, construction and operation of subsurface wastewater absorption systems serving community-scale developments. It is clear that the practices used for community systems cannot be as arbitrary or casual as those used for individual home systems. Pending the results of further research and experience, the following modifications to small-system practices are suggested for community-scale wastewater absorption systems on a single site:

Site Evaluation

The site evaluation should be performed by a trained professional (e.g., soil scientist experienced in siting and conceptual design of large wastewater absorption facilities). Detailed soil morphological inspections should be conducted to a depth of at least 2 m below the proposed infiltrative surface, with special attention devoted to [illegible]tical permeability characteristics. The groundwater hydrology should be addressed to enable estimation of any hydraulic impacts due to different wastewater absorption system design concepts and to ensure that excessive groundwater mounding will not occur. The local groundwater hydrology is also important as it may affect the purification requirements established for a given wastewater absorption system. The depth to flow restricting or limiting conditions can affect both infiltration/percolation and purification. Sufficient unsaturated soil depth should be available to allow for groundwater mounding and facilitate soil aeration.

Design

The design flow should be based upon a population projection with adequate provisions for infiltration/inflow. Since hydraulic load is critical to system performance, wherever possible, flow monitoring should be conducted to adequately characterize the wastewater flows. Design infiltration rates should be cautiously selected based on performance requirements, soil morphology and the hydraulic capacity of the entire site. The length to width ratio of the absorption area should be maximized with trench configurations as opposed to bed systems used wherever possible. The absorption system infiltrative surface should be installed as shallow as feasible to take advantage of biologically and chemically active soil zones and to maximize aeration. The wastewater absorption system should be sized for at least 150 percent of the design flow to enable routine long-term resting. At least three separate absorption cells should be provided to enable alternating service and prolonged resting of individual cells.

System Installation

Installation should be accomplished in as short a time period as feasible. Extended exposure of the subsoil infiltrative surface should be avoided. The driving of any construction machinery (tired or tracked) over the soil infiltrative area, even if covered by a layer of gravel or sand should be prohibited.

System Operation and Monitoring

The absorption units should be periodically rotated out of and back into service. The resting periods should be at least six months long and rotation should be avoided during cold weather seasons. All absorption units should be inspected at least monthly to determine their operational status and the occurrence and magnitude of continuous ponding. The wastewater hydraulic loading to each absorption unit should be monitored at least monthly to determine the average daily loading. The composition of the applied wastewater should be characterized during initial operation and at least annually thereafter. The constituents analyzed for should be carefully selected to provide useful data at least cost.

The elevation of the shallow groundwater beneath the absorption system should be monitored to determine the hydraulic impacts of the system and ensure that there is sufficient unsaturated soil depth. In light of the applied wastewater characteristics and the local soil and groundwater conditions, a ground water monitoring program should be established to ensure that acceptable purification is achieved. Appropriate groundwater monitoring programs may vary widely depending on site specific factors as will the judgement regarding acceptable purification.

SECTION 4

CURRENT PRACTICES

A survey of regulatory agencies was conducted to obtain information about large soil absorption systems. State and local regulatory agencies in 33 states were contacted and information was solicited to enable characterization of the distribution, regulatory structures, design restrictions, state attitudes and policies and the general experience associated with large soil absorption systems. The results of this survey are summarized in Table 1.

DISTRIBUTION

As Table 1 indicates, every state contacted had at least a few large soil absorption systems. However, these were mostly for single structures such as schools, hospitals or other large institutions. Some large systems served many hook-ups, most frequently trailer parks, campgrounds or recreational vehicle parks. In all cases, the number of large systems was relatively small. States usually claimed to have a limited number of institutional or commercial systems and maybe ten to twenty trailer parks. Seven states were exceptions to this generalization. Washington, Missouri, Maryland, Virginia, Utah, West Virginia and Wisconsin reported they had many systems serving institutions, commercial buildings, or mobile home parks. Systems serving institutions and mobile home parks tended to be conventional disposal fields or trenches, with common septic tanks and gravity sewers.

Seventeen states were identified to have large soil absorption systems serving multiple-home developments. An additional nine states were considering applications for such systems, or had already approved the designs. These systems did not usually serve an entire community but rather subdivisions or vacation areas. Vermont, South Dakota, Kentucky, Washington and Wisconsin all had community systems in the ground, designed or proposed. Some had received EPA construction grants funding. Some residential cluster systems had common septic tanks while others employed individual tanks. While conventional disposal fields or trenches were most common, some systems were mounds or evapotranspiration beds.

REGULATORY STRUCTURES

Regulatory structures varied from state to state. For the most part, regulation of large soil absorption systems was shared between state and local agencies. At the state level, jurisdiction was frequently shared by health and environmental agencies. With the exception of two or three states, most states had codes or guidelines for subsurface disposal. The most common regulatory vehicle was a permit, issued either by the state or local agency.

Individual residential systems and smaller institutional or commercial systems were usually regulated at the local level and the design was usually based on gallons per day, number of hook-ups, or, number of people served.

Table 1. Results of a 1981 Survey of Practices Associated with Large Soil Absorption System.

	SPECIAL LSAS CODE	INSTITUTIONAL LSAS	MOBILE HOME PARKS LSAS	MULTIPLE HOME LSAS	PERMIT REQUIREMENTS
Alabama	no	f		0	
Arizona	no	f	f	0	>1 house
California	no	s	s	s	Counties and regional water quality boards permit
Colorado	no	s	s	1	> 2,000 gal.
Connecticut	no	s	s	m	> 5,000 gpd. and engineer design
Florida	yes			1	(monitoring required)
Georgia	no	s	7	0	
Idaho					yes
Iowa	no	s	s	0	>15 houses and engineer design
Kansas	no	s	36	0	Public sewer district
Kentucky	yes	f	f		>1 house
Maine	yes	s	s	0	> 2,000 gal and engineer design
Maryland	no	m	m	s	
Massachusetts	yes	f	f		(<10,000 gpd)
Minnesota	no		15	s	Engineer design if >5,000 gpd and >15 units
Mississippi	no	f	f	0	
Missouri	yes	m	m	s	>10 houses and engineer design
Montana	no			10	
Nebraska	no				>50 people
Nevada	no	s	s	2	>5,000 gpd and engineer design (state ground water discharge permit if >10,000 gpd)

Table 1. Results of a 1981 Survey of Practices Associated with Large Soil Absorption Systems (Continued).

	SPECIAL LSAS CODE	INSTITUTIONAL LSAS	MOBILE HOME PARKS LSAS	MULTIPLE HOME LSAS	PERMIT REQUIREMENTS
New Hampshire		f	f		
New Jersey					>50 homes engineer design if >8,000 gpd)
New Mexico	yes	s	f	f	>2,000 gpd and engineer design
New York	yes			f	
N. Dakota	no	f	f		
Ohio	no	s		0	
Pennsylvania	no			f	yes
Rhode Island				0	>5,000 gpd (<10,000 gpd)
S. Dakota	no	f	f	1	>1 house and engineer design
Tennessee	no	f	f		
Utah	yes	m	m	0	yes
Vermont		s	s	3	Certified operator state permits, engineered sewage district
Virginia	no	s	m	f	>5,000 gpd and and engineer design
Wisconsin	no	s	m	s	yes
Wyoming		s	s		>1 house and engineer design

LSAS = Large soil absorption systems

LEGEND:
f = few
s = some
m = many

States frequently maintained the authority to regulate large systems. The minimum size for this shift of jurisdiction ranged from 2,000 to 8,000 gaL/d (7.6 to 30.3 m^3/d) on a flow criteria, from two to fifty households on a number of connections basis or, in one state, over fifty persons on a population served criteria.

Some states split their regulatory authority between environmental and health agencies with the basis being system size or ownership. State health departments generally regulated the smaller, private systems while environmental agencies handled large private and community systems. Five states had no legal authority over subsurface disposal unless it was a community system. At least one state, Missouri, theoretically regulated all systems with more than 10 individually owned residences, but lacked the personnel to enforce the regulation. Consequently, the state only reviewed the plans when developers chose to submit them.

Most states had codes and guidelines governing the design and installation of subsurface soil absorption systems. However, relatively few had separate regulations for large systems. Usually developers had to simply scale up the guidelines for single dwellings. While states generally didn't have large system codes, they often required that larger systems be engineered, and that designs be carefully reviewed by their agency. In contrast, smaller systems were often installed by a contractor, with no engineering plans, and little or no regulatory review. Community-scale systems were reported to be carefully engineered and closely scrutinized. In some cases the regulating agency was intimately involved in the design. Community systems were often required to obtain NPDES-type permits and some states required larger systems to obtain groundwater discharge permits.

DESIGN AND OPERATION REQUIREMENTS

States did not normally impose siting or design requirements on large systems other than those defined in their general subsurface disposal codes. Engineers were usually allowed to propose what they deemed to be good engineering practice for state review and approval. There were a few regulations directed specifically at large systems. Several states required that the design include the identification of a site for replacement of the initial system should it fail or that the initial system be built to accommodate twice the anticipated flow. Some states and counties imposed both these rules, while others required alternating fields, or dosing. Only one state required that systems have common as opposed to individual septic tanks, although states usually preferred one method or the other.

Other limitations concerned use or size. A few states limited size by policy to 20,000 gaL/d (75.7 m^3/d). Ohio prohibited cluster systems unless they were funded through the construction grants programs, and one regional water quality agency in California prohibited all commercial subsurface absorption systems. Opposition was often based on the agency's concern about the problems of multiple ownership.

To ensure proper operation and maintenance some states imposed an institutional restriction on cluster systems. Often developers were required to form homeowner's associations or get the county or city to form a sewer or special improvement district in order to get state approval. In some cases, bonds were required to be posted. In others, special districts had to have the power to tax, or assess homeowners for maintenance costs. Similarly, some states insisted that systems have licensed or certified operators, and others required groundwater monitoring programs.

STATE ATTITUDES AND POLICIES

State reactions to the use of large soil absorption systems were neither markedly positive or negative. Only Connecticut, Minnesota, Maine and Vermont encouraged such systems while twelve, or a little over a third of the states contacted were discouraging them. Some states did not think large systems were technically feasible. A number of states reported that large systems were impractical due to local soil or groundwater conditions. Mississippi, Kansas, and North Dakota fell into this category. Community systems were considered unnecessary in Nebraska, where their zoning commonly required a minimum lot size of 3 acres. Nevada discouraged large systems because the state was concerned that failures would lead to public health problems.

GENERAL EXPERIENCE

The survey revealed that state agencies have little experience with subdivision or community soil absorption systems. Most of these systems have not been in place long enough to enable adequate evaluation. Those that have been designed and installed in recent years "appear" to be working well. However, since most of the states where clusters are located lack both the funding and the manpower to monitor such systems, evaluation of their performance is impossible using existing data.

States have had years of experience with large soil absorption systems serving institutions and trailer parks, some as old as twenty years. These systems have reportedly performed well. The failures that have occurred to date tend to be systems that were improperly designed, not designed at all, improperly sited, or poorly maintained. Most frequently noted problems were associated with the past. Many states did not require engineering designs for systems of this type. Developers simply installed off-the-shelf designs, without adequate evaluation of soil and site conditions. Another common problem was overloading. For example, trailer park owners would install systems for a specific number of pads, then expand their facility, without making alterations to the wastewater handling facilities.

SECTION 5

PERFORMANCE EVALUATION OF THE COMMUNITY SOIL ABSORPTION SYSTEM AT WESTBORO, WISCONSIN

The field monitoring efforts of the overall study were concentrated on the community soil absorption system at Westboro, Wisconsin (Otis, 1978; Otis and Fey, 1981). Westboro is a community of approximately 205 persons located in northern Wisconsin (Figure 2). Until 1977, all buildings in the community were served by private septic tank systems. With over 80 percent of these systems malfunctioning, the Town of Westboro investigated alternative wastewater management options. During the Summer of 1977, public wastewater facility was constructed. It included a system of small diameter gravity sewers for conveying the effluent from septic tanks serving each building to a community subsurface wastewater absorption system.

Monitoring of the wastewater absorption system occurred over a two-year period between June 1981 and May 1983. Data were collected regarding system design and performance:

0 Wastewater facilities design
0 Soil and site characteristics
0 Applied wastewater characteristics
0 Soil infiltrability
0 Subsystem soil moisture conditions and gas composition
0 Groundwater characteristics
0 Surface water characteristics

The results of this work ave summarized in this section. Additional details may be found in Appendix A of this report.

WASTEWATER SYSTEM CHARACTERISTICS

The wastewater facilities were comprised of individual septic tanks, small diameter gravity sewers, a siphon-dosing system and three large subsurface wastewater absorption beds. The absorption beds were each 100 ft (30.5 m) by 130 ft (39.6 m) in area (Figure 2). They were sized for a 1.2 gal/ft^2/d (5 cm/day) hydraulic loading rate which was determined from an examination of soil morphology and the results of standard percolation tests. Each bed was designed to receive 50 percent of the design daily flow or 15,000 gal/d (56.8 m^3/d) per bed, so that at any time, only two beds would be needed and the third could be rested. The beds were installed such that their bottom infiltrative surfaces were at a depth of 42 - 49 in (1.1 to 1.4 m). Each bed was filled with 18 in (0.5 m) of stone and then backfilled with natural soil materials from the site. A siphon-dosing system and pressure-distribution networks were utilized to automatically distribute septic tank effluent throughout the beds. Twelve observation vents (4-in diameter) extended from the bottom of each bed to roughly 1 m above the final ground surface. The wastewater absorption beds were constructed during the Summer of 1977 and put

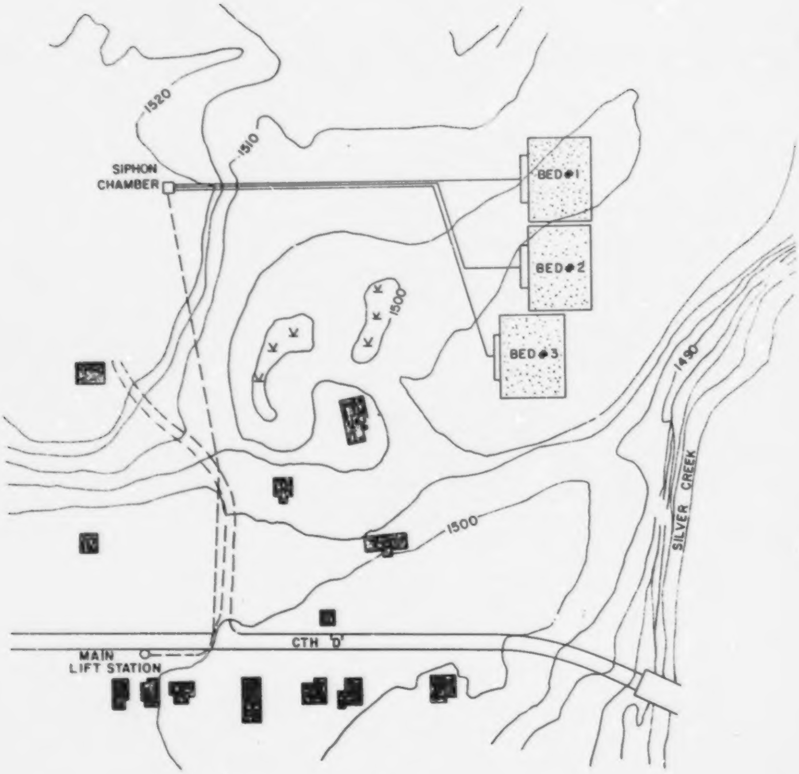

1520
1510
SIPHON CHAMBER
BED#1
BED#2
BED#3
1500
1490
SILVER CREEK
1500
CTH 'D'
MAIN LIFT STATION

Figure 2. Location of Soil Absorption Beds at Westboro, Wisconsin (Otis, 1978).

into operation in September, 1977. During the course of this study, Beds 2 and 3 (Figure 2) were in service.

SOIL AND SITE CHARACTERISTICS

The wastewater absorption beds were located on a gently sloping glacial outwash terrace adjacent to a small stream (Figure 2 and 3). Inspection of backhoe pits showed the soils to be highly variable vertically and laterally. Soil profiles in the northern one-third to one-half of the site were dominantly very fine sands and silts which were complexly interbedded with layers of coarser sands and gravels. These finer deposits consisted of very well-sorted particles mostly in the 0.02 to 0.20 mm size range, often compact and resistant to vertical flow. Laboratory measurement confirmed their low permeabilities with saturated hydraulic conductivity (k_{sat}) values as low as 10 cm/d. By contrast, the medium to coarse sands and gravels were estimated to have K_{sat} values of 500 to 1000 + cm/d. The soils of the southern half of the site were distinctively more sandy and less interbedded. Although some stringers of very fine sands and silts were observed, they appeared to be thin and discontinuous. Vertical permeabilities of these materials were judged to be much greater than that in the northern half of the site due to the vertical continuity of the coarser materials.

Particle size distribution data were determined for selected soil samples representing the range of deposits present. Samples of the finer, more hydraulically restrictive deposits were classified texturally (USDA) as fine sands, sandy loams and loams. Three of these samples contained content of particles smaller than 0.5 mm (medium sand) of greater than 98 percent, although clay content in each case was less than 1 to 15 percent.

The permeability of the soil system was estimated according to standard percolation test procedures (U.S. EPA, 1980; Wis. Adm. Code, 1980). Percolation rates ranging from 25 to 8 min/in (140 to 470 cm/d) were measured in the northern half of the site at three locations with considerable interbedding of fine and medium sands. In contrast, percolation rates measured prior to system construction at three locations in more permeable materials in the southern half of the site were all less than 2 min/in (2150 cm/d) (Table 2). Saturated conductivity measurements were conducted on selected soil samples in the laboratory utilizing concentric-ring permeameters (Hargett, 1982). A loam sample displayed a low K_{sat} of 9.5 cm/d while a very fine sandy loam sample had a K_{sat} of 86 cm/d. Two fine sand samples yielded K_{sat} values of 247 and 366 cm/d (Table 3). These conductivity data confirmed the relatively low permeabilities of the fine, well-sorted, compact materials observed in the field during the soils investigations.

WASTEWATER FLOW AND COMPOSITION

The average daily wastewater flow at Westboro was determined by recording the discharge cycles of the siphons delivering STE to the soil absorption beds. Based upon measurements made between June 1981 and October 1982,

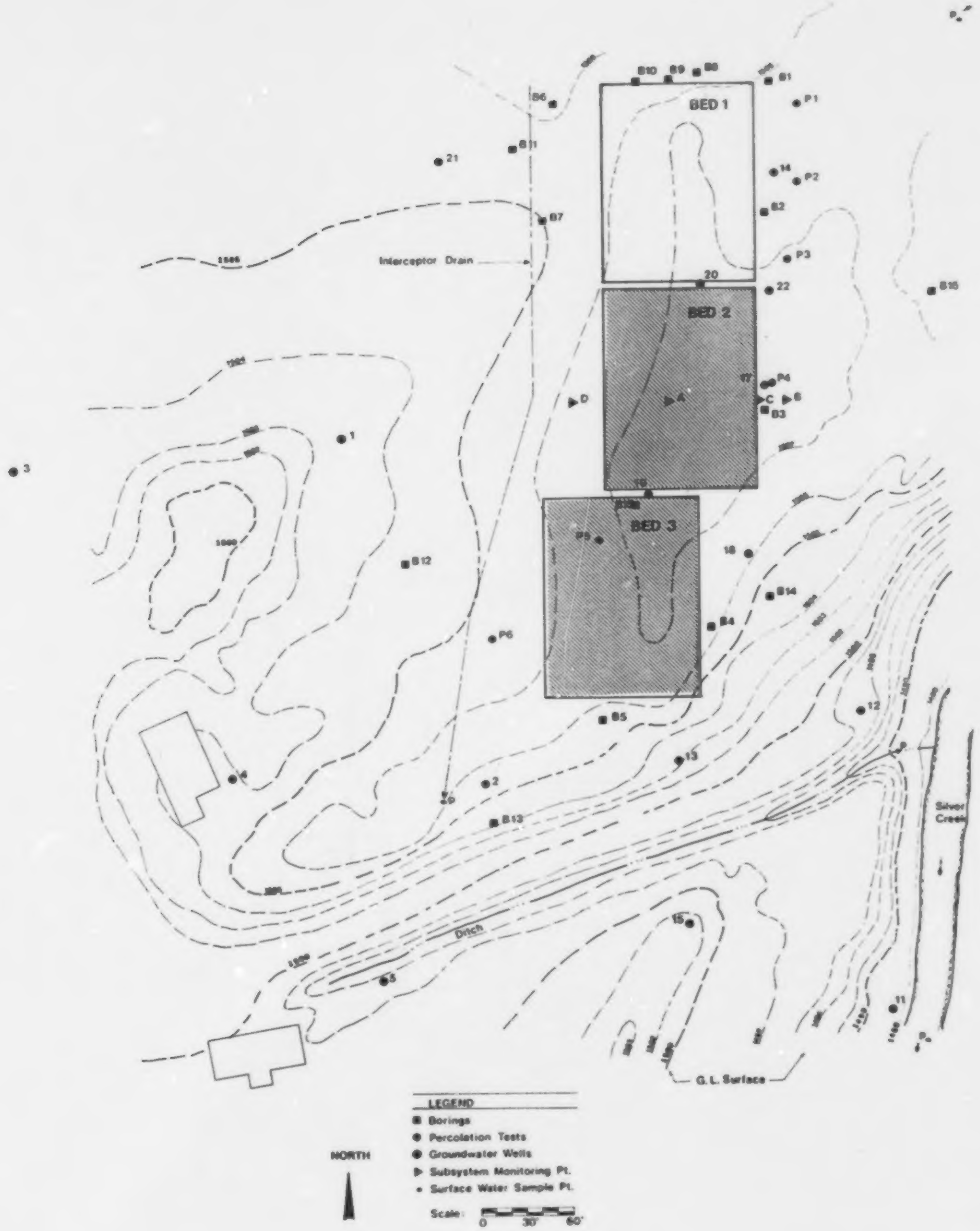

B10
B9
B8
B1
B6
P1
BED 1
21
B11
14
P2
B2
B7
1586
Interceptor Drain
P3
20
22
B16
BED 2
17
P4
D
A
C
E
B3
1
3
19
BED 3
P5
18
B12
B14
B4
P6
12
B5
13
4
2
D
B13
Silver Creek
15
Ditch
5
11
G.L. Surface
LEGEND
Borings
Percolation Tests
Groundwater Wells
Subsystem Monitoring Pt.
Surface Water Sample Pt.
NORTH
Scale:
0
30'
60'

Figure 3. Location of Soil Evaluation Points and Monitoring Instruments at Westboro, Wisconsin.

Table 2. Percolation Test Results.

Test No.*	Depth Below** Grade - m (ft)	Soil Stratum		Percolation Rate		Date
		Sidewall	Underlying	min/in	cm/day	
P1	1.07 (3.5)	ms	hsil-vfsl	25	145	10/21/81
P2	1.07 (3.5)	cs (near saturation)	hsil (dry)	16	229	10/21/81
P3	1.22 (4)	cs	vfsl-l	7.8	469	10/21/81
P4	1.07 (3.5)	sl	sl	1.7	2150	8/05/76
P5	1.07 (3.5)	fs	fs	1.1	3325	8/05/76
P6	1.07 (3.5)	sl	sl	1.2	3050	8/05/76

* See site plan (Figure 3) for test locations.

** Bottom of all percolation test holes at or slightly above elevation of systems' infiltrative surface (i.e. 458 m [1502.7 ft], except P6 about 0.5 m [1.8 ft] below).

Table 3. Saturated Hydraulic Conductivity of Soil Samples.

Boring No.*	Depth Inches (cm)	USDA Texture	≤fs (%)	K_{sat} (cm/day)	Density (g/cm^3)**
B2	32-36 (81-91)	l	97.6	9.5	1.48
B2	44-49 (112-125)	fs	80.4	366.3	1.60
B2	64-80 (163-203)	fs	66.9	246.6	1.60
B7	46-64 (117-168)	vfsl	99.3	85.6	1.52

* See site plan (Figure 3) for boring locations.

** Disturbed samples hand-packed to maximum dry-density.

approximately one siphon discharge occurred daily representing an average daily flow of 8,500 gal/d (32.2 m^3/d). During this study, Beds 2 and 3 were used exclusively while Bed 1 was rested. With two absorption beds in service, the average daily flow resulted in a STE application rate of approximately 1.4 cm/d (0.33 gpd/ft^2) of bottom area. Under normal operation, the siphon would alternately discharge 2.8 cm (0.65 g/ft^2) to each operating bed, but only every other day.

The composition of the STE was determined from grab samples collected from the siphon chamber between September 1981 and May 1983 (Table 4). Wastewater composition included substantial concentrations of biochemical oxygen demand (168 mg/L), suspended solids (85 mg/L), ammonia nitrogen (44 mg-N/L) and fecal coliforms (2.0 x 10^7 org./L). The measured composition was substantially similar to that reported by earlier investigators (Table 4).

SOIL INFILTRABILITY

The infiltrability of the wastewater absorption beds was indirectly measured through monitoring the occurrence and magnitude of STE ponding. Records indicated that ponding was noted in all three beds as early as June 1979, less than two years after start up. The first measurements of this study were made in June 1981. These revealed high levels of ponding. Bed 2 and 3 were in service at the time and both were found to have approximately 46 cm (18 in) of STE ponded above their bottom infiltrative surfaces. During the course of the study, the level of ponding fluctuated somewhat, but both operating beds remained nearly fully ponded.

The average daily STE application rate was calculated at 1.4 cm/d based upon bottom area alone. Assuming all of the STE applied to the beds under normal operation infiltrated into the bottom of the beds, the 1.4 cm/d can be viewed as roughly equal to the infiltrability of the absorption system. This 1.4 cm/d rate was less than 50 percent of an apparently conservative design loading rate of 3.0 cm/d for this site based upon the slowest percolation rate measured in this study.

During the installation of subsurface monitoring instruments in Bed 2, the infiltrative surface was visually inspected and sampled. At both locations within the bed (Figure 3, Point A, C), the gravel was found to be embedded with the natural sand surface. The infiltrative surface did not exhibit a surface clogging mat as such. The sandy soil was black in color to a depth of approximately 5 to 8 cm and was quite wet. At 15 to 20 cm depth, however, the sand had graded to natural coloration and was only moist. These observations were consistent with those of previous investigators (Bouma, 1975; Anderson et al, 1982).

Soil samples were collected with depth during installation of a groundwater observation well at Location A (Figure 3). Very high volumetric moisture contents (33.9 and 37.8%) were measured in the upper 10 cm of soil immediately beneath the bottom of the bed. With the total soil porosity

Table 4. Comparison of Septic Tank Effluent Composition As Determined by Various Investigators*

		Multiple Homes					Individual Homes		
Parameter	Units	Westboro, WI	Bend, OR	Glide, OR	Manila, CA	College Sta., TX	Wiscon-sin	Pennsyl-vania	Oregon
BOD_5	mg/L	168	157	118	189	-	132	-	217
COD	mg/L	338	276	228	284	266	445	483	-
TS	mg/L	663	-	376	355	-	895	-	-
TSS	mg/L	85	36	52	75	-	87	108	146
TKN	mgN/L	57	41	50	-	29.5	81.5	74.4	57.1
NH_4	mgN/L	44	-	32	-	24.7	53.5	-	40.6
NO_3	mgN/L	6.4	-	0.5	-	0.2	0.95	<0.33	0.42
TP	mgP/L	8.1	-	-	-	8.2	21.8	18.2	-
pH	-	6.9-7.4	6.4-7.2	6.4-7.2	6.5-7.8	7.36	7.3	-	-
CL-	mg/L	62	-	-	-	1.83	164	230	-
EC	umhos/cm	1073	-	-	-	3204	909.8	-	-
Grease	mg/L		65	16	22	-	-	-	-
F. Coli-forms	Log#/L	7.3	-	-	-	6.04	6.45	-	6.41
F. Strep-tococci	Log#/L	5.7	-	-	-	-	5.40	-	-
Flow	Lpcd	136	151-227	182	151-216		166	-	-

* Descriptions

Westboro, WI - Small diameter gravity sewer collected STE from a small community.
Bend, OR - Pressure sewer collected STE from 11 single family homes (Bowne, 1982).
Glide, OR - Pressure sewer collected STE from a small community (Bowne, 1982)
Manila, CA - Pressure sewer collected STE from 330 connection (Bowne, 1982).
College Sta., Texas - Ste from one septic tank serving 9 homes (Brown, et al., 1977)
Wisconsin - 33 single family homes in Wisconsin (Harkin, et al., 1979)
Pennsylvania - 10 single family homes in Pennsylvania (Cole and Sharpe, 1981)
Oregon - 8 single family homes in Oregon (Ronayne, et al., 1982)

estimate at 40 percent, these data suggest that nearly all of the soil pores were waterfilled. Below this, at 15 to 20 cm, a much lower moisture content was measured (24.8%). The accumulations of volatile matter (TVS) and nitrogen (TKN) were most pronounced in the soil near the infiltrative surface and decreased with depth. Similar findings have been reported previously (Kristiansen, 1981).

Infiltration of septic tank effluent into soil materials is known to result in soil clogging which leads to large reductions in soil infiltrability. In sands, the primary cause appears to be accumulation of wastewater suspended solids and microbial cell mass and metabolic by-products. Long-term infiltration rates are supposedly used in system design to account for these reductions and represent the infiltrability of a mature, clogged soil system.

The work of Bouma (1975) led to the widespread acceptance of design infiltration rates for subsurface wastewater absorption systems based upon four major soil types; I - sands, II - sandy loams, loams, III - silt loams, some silty clay loams, and IV - clays, some silty clay loams (Bouma, 1975; EPA, 1980; Anderson et al., 1982). Review of Bouma's results raised questions regarding the design infiltration rate for systems installed in sandy soils which contain substantial percentages of finer sands, silt or clay matter. The results of Bouma (1975) for the coarse sands studied support a recommended design infiltration rate of 5 cm/d. However, the results regarding sandy loams were variable and do not support a 3 cm/d recommended rate. The work of Simons and Magdoff (1979) supports lower design infiltration rates for sandy soils of other than coarse texture. These investigators recommended a maximum safe infiltration rate of 2 cm STE per day for sands based upon column studies with a sand containing 33 percent medium and 54 percent fine particles. Otis and Hargett (1983) have also advocated conservative loading rates. The results of the study at Westboro suggest that even 2 cm/d may be too high for large bed systems installed in fine sands.

SUBSYSTEM CHARACTERISTICS

Monitoring instruments were installed at four locations within or near Bed 2: 5.1 m outside the west edge (Pt. D), near the center (Pt. A), at the east edge (Pt. C) and 5.1 m outside the east edge (Pt. B) (Figure 3). These included groundwater observation wells, and soil moisture tensiometers and pore gas samplers at approximately 30 cm and 75 cm below the bottom of Bed 2.

Soil moisture tensions (SMT's) beneath Bed 2 were similar at both depths below the infiltrative surface suggesting that flow in the soil was at unit gradient. Under the Bed, the SMT's ranged from 21 to 44 cm (Table 5). The resistance to infiltration, R_b, was calculated according to the method of Bouma (1975) to equal approximately 60 days. These SMT and R_b values are similar to those measured by Bouma.

Table 5. Soil Moisture Tensions (SMT) Beneath Bed 2*.

Date/Parameter	Units	Location					
		Center (A)		Edge (C)		Outside (B)	
		Shallow	Deep	Shallow	Deep	Shallow	Deep
August 3, 1982							
SMT +	CmH_2O	44	35	28	37	43	39
Distance Above Water Table#	Cm	91	42	120	73	208	158
August 24, 1982							
SMT	CmH_2O	34	40	36	44	51	61
Distance Above Water Table	Cm	106	58	135	88	220	170
October 12, 1983							
SMT	CmH_2O	21	21	21	21	0	39
Distance Above Water Table	Cm	83	35	105	58	212	162

* Refer to Figure 3 for instrument locations.
+ SMT = Soil moisture tension.
# Distance above water table = instrument elevation - groundwater elevation.

Table 6. Soil Gas Composition Beneath Bed 2*.

Parameter	Unit	Distance Below Infiltrative Surface	
		30 cm	75 cm
Soil Moisture Tension	CmH_2O	21	21
Pore Gas - CH_4	%	19.1	17.9
- CO_2	%	3.8	4.1
- O_2	%	1.3	0.2
- N_2	%	70.8	72.4

* Data shown were collected on October 12, 1983 beneath center of Bed 2 (Figure 3, Location A). Distance to water table was 107 cm.

Samples of soil pore gas were collected at the same locations at which the SMTs were measured. Concentrations of CH_4 gas were 19.1 and 17.9 percent at 30 and 75 cm depths beneath the infiltrative surface of the bed, respectively. Concentrations of CO_2 gas were 3.8 and 4.1 percent at these same depths (Table 6). Both of these gases are produced as a result of microbial fermentation under anaerobic conditions. Concentrations of CH_4 and CO_2 measured at the edge of the bed were similar to those measured beneath the bed, suggesting that little horizontal diffusion of O_2 was occurring from the natural soil surrounding the bed or that it was insufficient compared to the O_2 demand exerted. These results were unexpected based upon the results of earlier investigators (Walker et al., 1973; Sikora and Corey, 1976) which indicated aerobic conditions beneath subsurface wastewater absorption systems. However, previous work had addressed only small single-home systems. Siegrist et al. (1984) suggested that subsystem anaerobiosis may characterize large bed systems.

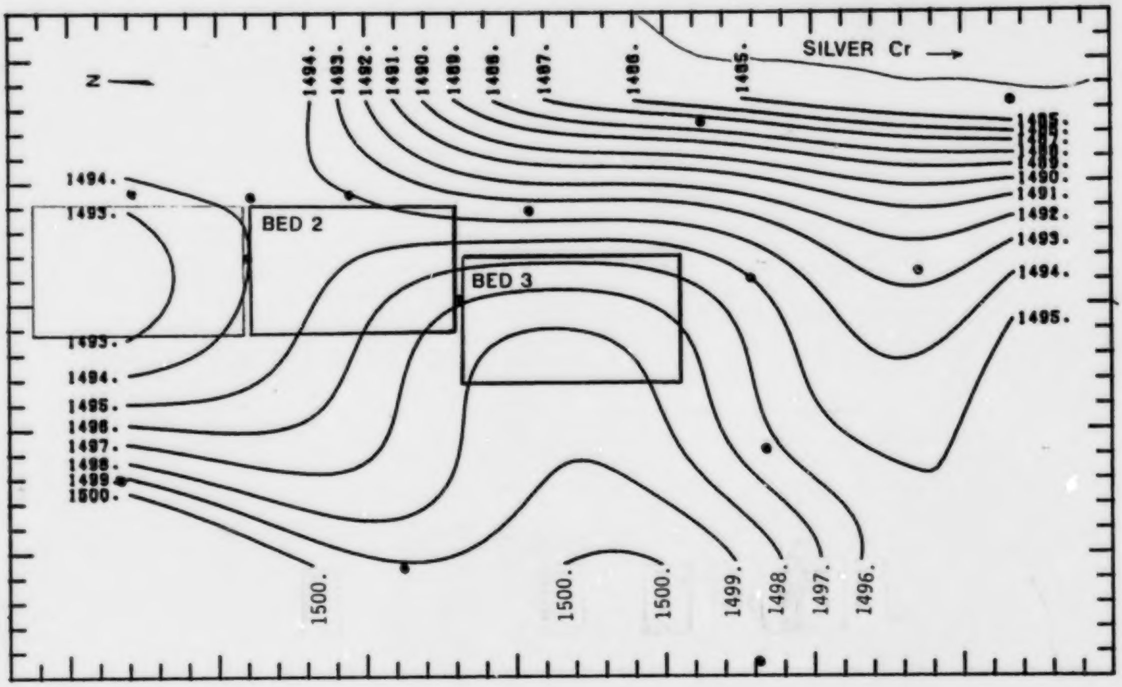
GROUNDWATER CHARACTERISTICS

Surface Elevations and Flow Patterns

The groundwater in the vicinity of the absorption beds was thoroughly characterized using 27 existing monitoring wells (Otis, 1978; Appendix A). These included wells at 16 locations around the site with nests of two to three wells at different depths at seven of the locations (Figure 3). Sixteen shallow observation wells (2.4 m maximum penetration) located across the site were used to measure groundwater surface elevations. To delineate the groundwater surface and to estimate groundwater flow patterns a multi-dimensional spline smoothing routine was coupled with a computer contour plotting routine and graphics system to obtain computer drawn groundwater contour maps (MACC, 1981; Anderson et al., 1984).

Representative groundwater surface elevations near the system are shown in Figure 4. Although elevations fluctuated seasonably about 60 cm, contour patterns stayed very much the same and indicated multi-directional groundwater flow under the absorption beds. The general flow pattern was as expected based upon surface topography which slopes from northwest to southeast (Figure 2). In addition, the groundwater surface was elevated in an area extending from west of Bed 3 to under it with groundwater flow radiating out to the northeast, east and southeast (Figure 4). This pattern suggested that a small recharge area existed west of bed 3. A low-lying marshy area was located approximately 61 m (200 ft) west of Bed 3 and could have been partly responsible for the pattern indicated. This could also have been caused by surface water flowing downslope over restrictive horizons until encountering vertically permeable soil conditions near Bed 3.

Mounding of groundwater beneath the absorption beds was estimated to be 18 cm using a model developed by Finnemore and Hantsche (1983). In contrast to this estimate, inspection of the groundwater contour plots suggested that groundwater mounding may have been higher. Groundwater elevations measured


N
SILVER Cr
1494.
1493.
1492.
1491.
1490.
1489.
1488.
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1486.
1485.
1485.
1486.
1487.
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1494.
1495.
BED 2
BED 3
1494.
1493.
1493.
1494.
1495.
1496.
1497.
1498.
1499.
1500.
1500.
1500.
1500.
1499.
1498.
1497.
1496.

Figure 4. Computer Generated Plot of Groundwater Surface Elevation on August 27, 1981 (1 unit = 3.75 ft).

along a west to east transect under Bed 2 were interpreted to suggest a potential maximum mound of approximately 60 cm under the center of Bed 2. The discrepancy between the field results and the model predictions are believed to be due to the heterogenous, anisotropic character of the subsystem soil conditions at Westboro and the potential site variability of the estimated model parameters.

Groundwater Composition

The composition of the groundwater in the vicinity of the wastewater absorption beds was determined through sampling of 25 groundwater monitoring wells (Figure 3). The multi-dimensional spline smoothing routine was applied to an extensive groundwater database to map contour levels for the parameters measured. Details of this analysis may be found elsewhere (Anderson et al., 1984; Appendix A). A synopsis of the groundwater quality impacts is presented below. Throughout the groundwater monitoring period, the water table surface varied in elevation but remained 75 to 200 cm beneath the bottom of the absorption beds.

The monitoring wells located closest to the absorption beds revealed significant increases in the concentrations of measured parameters in the groundwater relative to background levels (Tables 7-8). In particular, samples from the shallow wells located near and downgradient from Beds 2 and 3 exhibited mean concentrations of total dissolved solids, chlorides and conductivity not significantly different ($\alpha = 0.05$) from the concentrations in the applied STE. These concentrations of conservative parameters indicated that the monitoring wells were installed so that samples were withdrawn within the effluent plume.

The mean ammonia nitrogen concentrations measured near the beds were approximately 100 times greater than background levels and not significantly different from the NH_4 concentrations of the applied STE (Table 8). These data indicated that little nitrification was occurring presumably as a result of anaerobic conditions. The mean concentrations of phosphorus (P) measured near the beds were not significantly different than background levels (Table 8). Mass balance calculations indicated a reasonable P immobilization of about 100 µg/g of soil (Sikora and Corey, 1976). Mean concentrations of chemical oxygen demand (COD) varied from 37 to 86 mg/L compared to 338 mg/L in the applied STE and 5 mg/L in the background groundwater (Table 8). The maximum concentration of fecal coliform bacteria measured near the beds was 8 organisms/100 mL, a value equal to or lower than that measured in the background wells.

The groundwater quality degradation exhibited in the immediate vicinity of the beds appeared to be limited to the upper zone of the groundwater. For example, samples collected from nested wells at location 13 exhibited decreasing levels of the measured parameters with increasing depth. The groundwater composition measured in the deepest well (6.4 m deeper than the shallow well) approached that of the background groundwater.

Table 7. Mean Concentration of Conservative Parameters in the Groundwater Across and Downgradient from the Absorption Bed Site.

Location	Distance** m	TDS mg/L	CL- mg/L	Cond. µmho/cm
Well 1-3	53.0	170	14.3	150
Applied Wastewater	-	576	62	1073
Well 13-3	17.1	495	65	1015
Well 18	9.1	467	63	1025
Well 19	0.8	480	66	960
Well 12	32.0	407	25	551
Well 11	82.3	216	3.9	207

* Refer to Figure 3 for well locations.

** Approximate horizontal distance from closest edge of Bed 3.

Table 8. Mean Concentrations of Potential Pollutants in the Groundwater Across the Absorption Bed Site.

Location*	Distance** m	TKN mg-N/L	NH_4 mg-N/L	NO_3 mg-N/L	TP mg-P/L	COD mg/L
Well 1-3	53.0	0.62	0.21	2.74	0.08	5
Applied Wastewater	-	57	44	6.4	8.1	338
Well 13-3	17.1	50.1	45.7	2.50	0.11	69.5
Well 18	9.1	49.3	41.5	4.28	0.12	47.5
Well 19	0.8	40.6	33.1	1.64	0.10	75
Well 12	32.0	1.2	0.72	1.70	0.13	28.5
Well 11	82.3	0.68	0.15	1.51	0.07	<5

* Refer to Figure 3 for locations of wells.

** Approximate horizontal distance from closest edge of Bed 3.

Approximately 32 m (105 ft) downgradient from the edge of Bed 3 (Figure 3, Well 12), the concentrations of conservative parameters were lower than those measured next to the beds but still significantly higher than background levels (Table 7). The mean concentration of ammonia nitrogen measured at Well 12 was only 0.72 mg-N/L, but still significantly higher than the mean level at Well 1-3 of 0.21 mg-N/L. The mean concentration of phosphorus was not significantly different from background levels. The chemical oxygen demand (COD) measured in two samples from Well 12 were 19 and 38 mg/L compared to the 5 mg/L or less determined in two samples from Well 1-3, a background well. Fecal coliform bacteria were not detected in the groundwater samples extracted from Well 12.

The groundwater quality data from Well 12 revealed reductions in the elevated levels of potential pollutants as measured in the groundwater near the beds (Table 8). These data suggest that pollutant attenuation through dilution and dispersion or removal and degradation may have been achieved within the saturated zone. The groundwater as characterized at Well 11, approximately 82 m downgradient and adjacent to Silver Creek, exhibited a composition essentially equal to that of the background groundwater (Tables 7-8).

SURFACE WATER CHARACTERISTICS

Water quality monitoring was conducted in a nearby stream located within approximately 47.2 m (155 ft) of the southeast corner of Bed 3 (Figure 3). Monitoring both upstream and downstream revealed no degradation attributable to the wastewater absorption system.

PERFORMANCE ASSESSMENT

The site evaluation and design of the wastewater absorption beds at Westboro were judged adequate and accurate according to Wis. Code and the state of knowledge available at the time of their implementation (i.e. 1976-1977). According to these criteria, the majority of the two operating absorption beds (Beds 2 and 3) were located in areas well-suited for the systems as designed for a 5 cm/d long-term hydraulic loading rate, with regard to both infiltration and purification of STE.

The results of the soils investigations indicated the inappropriateness of using small diameter boreholes and simple percolation tests to assess site suitability and size large wastewater absorption systems. Inspection of stem cuttings from a flight auger or even an undisturbed core from a split spoon sampler may not have adequately revealed the hydraulically important but relatively thin interbedded layers of very fine sands and silts. Percolation rates determined through standard procedures likely reflect horizontal permeability and not the vertical permeability of the restrictive horizon(s). By example, the slowest percolation rate measured was 146 cm/d (25 min/in) compared to the < 10 cm/d K_{sat} measured by the CRP technique in the finer soils.

The performance of the wastewater absorption beds at Westboro was different than expected with regards to both infiltration and purification. Conventional practice, based primarily on experience with single-home systems, would have predicted an operating infiltration rate of 5 cm/d and aerobic conditions for wastewater renovation. At Westboro, the operating infiltration rate was estimated to be only 1.4 cm/d and anaerobic conditions were present under the system. Some localized degradation of the shallow groundwater beneath the beds has occurred. The reasons for this performance are believed to be associated with the bed geometry, stratified sandy soil materials, and shallow groundwater conditions.

The absorption beds at Westboro were large and square in geometry (30.5 m by 39.6 m each). As a result, minimal sidewall area was available for infiltration causing mostly vertical flow under a unit hydraulic gradient. The horizontal soil infiltrative surface consisted of gravel from the absorption beds intermingled with the natural sandy soil. This effectively reduced the available pore space for infiltration and percolation. Thus the apparent 1.4 cm/d infiltration rate may have been substantially higher if expressed per unit area of soil matrix only.

Subsystem anaerobiosis may also have contributed to intensified wastewater induced soil clogging and the low infiltration rates observed. The anaerobiosis results from a wastewater-induced oxygen demand exceeding the oxygen transfer capacity of the system. Besides the ponding over the soil surface, the oxygen transfer capacity was probably limited by the bed geometry, the 1.4 m infiltrative surface depth and the shallow groundwater beneath the beds (75 to 200 cm). All of these inhibit the supply of oxygen to the wastewater infiltrative surface.

The squarish bed geometry and shallow groundwater conditions probably contributed to the measured groundwater impacts. Aside from the lack of nitrification, the actual wastewater renovation achieved through soil treatment was similar to that anticipated. However the comparatively concentrated loading of adjacent beds and the shallow groundwater conditions no doubt led to the measurable impacts observed in this study. Regardless, more than 32 m (105 ft) downgradient from the absorption beds, the groundwater quality approached that of the groundwater upgradient from the system.

SECTION 6

FIELD EVALUATION OF MULTIPLE-HOME SOIL ABSORPTION SYSTEMS IN WASHINGTON STATE

In Washington during the 1970's, large subsurface soil absorption systems were increasingly utilized to treat and dispose of the wastewater from clusters of residential dwellings, typically single-family homes, condominiums, apartments or mobile-home trailers. Extensive use of these systems occurred in Spokane County in eastern Washington and Pierce County in western Washington. To gain further insight into the performance characteristics of large soil absorption systems, a number of these systems were investigated.

The selection of systems to be studied was made utilizing the following criteria:

- 0 The system served a subdivision or small community and included a septic tank and subsurface soil absorption system (trench, bed, or mound).
- 0 The system was designed and installed within the past five years according to accepted criteria.
- 0 The system was intended as a permanent wastewater facility for the service area and not an interim solution pending sewers becoming available.
- 0 The system was located in soils of sand or finer texture with the depth to limiting layer (e.g., groundwater, bedrock . . .) less than 10 feet.
- 0 The current flow was estimated to be at least 70% of the design flow.
- 0 The physical characteristics of the system enabled data collection and the owners and operators were willing to cooperate.

Approximately 22 systems serving multiple residential units were identified and of these, six systems were selected for study. The six study systems possessed the characteristics shown in Table 9.

The field investigation of these systems was not intended to be anywhere near as thorough as that conducted at Westboro, Wisconsin (Section 5). Rather, efforts were made at each site to determine the basic characteristics of the wastewater facility, the soil conditions, the applied wastewater and the absorption system performance. The results of this field study are summarized in this section.

Table 9. Characteristics of Six Systems Studied in Washington.

Name	Harbor Country Estates	Nesika Bay*	Tolmie Park Estates	Farwell Estates	Galen Park	Riegel Heights
County	Pierce	Kitsap	Thurston	Spokane	Spokane	Spokane
Dwelling Units						
Type	Apartments	Condos/Houses	Houses	Houses	Houses	Houses
Number	56	6/5	17	11	11	10
Design Flow (gpd)	16,100	2,437	7,650	3,850	3,850	3,500
Collection						
Type	Gravity	Gravity	Gravity	Gravity	Gravity	Gravity
Size (in. diam.)	6, 8	8	?	?	?	
Preatreatment						
Type	Septic Tank	Septic Tank	Ind. Septic Tank	Septic Tank	Septic Tank	Ind. Septic Tanks
Size (gal)	23,700 (2:15,800 + 7,900)+	8,000 (3)	1125/home (2)	4,500 (3:1,500 + 1,500 + 1,500)	4,100 (3:1,500 + 1,500 + 1,100)	1,000/home
Drainfield						
Type	Trenches	Trenches	Deep Trenches**	Trenches	Trenches	Trenches
Width (ft)	3	2	2	2	2	2
Length (ft)	100	100	100	100	100; 85	100
Number	54	18	15	7	4; 2	14
Area (ft²)	16,200	3,600	3,000	1,400	1,140	2,800
Soil#	Sand	Gravelly Sand	Loamy Sand	Loamy Coarse Sand	Loamy Coarse Sand	Gravelly Loamy Sand
Costs						
Construction ($)	64,125	-?	28,900	12,000	6,250	13,700
O/M ($/Yr/Unit)	90	60	78	40	19	0
System Age (Yr.)	4	4-5	4	5	2.5	4
O & M Responsibility	County Utilities District	Homeowners Assn.	Private Utility Manager	Homeowners Assn.	Homeowners Assn.	Homeowners Assn.

* Systems originally designed for 6 condos in 1978; drainfield expanded to size shown in 1979.
+ Indicates compartmentalization number and size (if known)
** 5' of gravel provided beneath distribution pipe.
++ Indicates number of laterals of length specified.
# Classification according to SCS.

SOIL AND SITE CHARACTERISTICS

All systems were installed on landscapes of 0 to 20 percent slope. The systems at Tolmie Park, Nesika Bay and Farwell Estates were installed on nearly level terrain. The remaining systems were installed on slopes of 10 to 20 percent.

Sieve analyses were performed on samples (0.9 - 1.8 kg) of soil materials obtained from the site of each of the six systems, generally from the approximate depth of the wastewater infiltration surface (i.e. trench bottom). As indicated in Table 10, the soil materials at all sites were generally of coarse texture. The percentage of finer particles (< 0.07 mm) was less than 13 percent at all sites except Riegel Heights where it was less than 20 percent (Table 10).

Soil permeability was estimated using standard percolation test procedures (U.S. EPA, 1980). Measured rates were typically less than 10 min/in (365 cm/d) (Table 10). These rates were consistent with those expected based upon the sand texture of the soil materials at the sites.

Restrictive layers (hardpan) were encountered below the Harbor Country, Nesika Bay and Galen Park systems at a depth of 0.9 to 2.4 m (3 to 8 ft). Based upon available resource materials, it was believed that Riegel Heights and Tolmie Park also had a hardpan or impermeable layer within 3.0 m (10 ft) of the surface.

APPLIED WASTEWATER CHARACTERISTICS

Average daily wastewater flows were determined at each site using water meters on the individual residences and/or elapsed time indicators on the pumps discharging effluent to the soil absorption systems. Due to uncertainties regarding the true discharge rates of the pumping systems, the elapsed time indicators generally did not yield useful data. At two sites, wastewater flows had to be estimated using representative residency and per capita flow information. As shown in Table 11, current wastewater flows were estimated to be approximately 1,375 to 7,000 gal/d (5.2 to 26.5 m^3/d), or 43 to 61 percent of the respective design flows.

The compositions of the septic tank effluent (STE) determined for each system are shown in Table 12. The compositions measured were generally within the range of values determined at Westboro and by other investigations (see Table 4). The total suspended solid (TSS) concentrations measured, however, were atypically low, less than 40 mg/L for five of the six sites. The TSS concentration at Galen Park was substantially higher at 102 mg/L, yet within the range of values reported elsewhere (Table 4).

Table 10. Particle Size Characteristics of Soil Samples and Field Percolation Rates.

Parameter	Harbor Country		Nesika Bay		Tolmie Park Estates		Farwell Estates		Galen Park	Riegel Heights	
	1	2	1	2	1	2	1	2	1	1	2
Particle Size (% by wt.)											
> 2.00 mm	35.4	20.4	76.9	15.4	49.2	55.5	39.4	36.0	14.1	14.4	12.0
> 0.42 - 2.00 mm	15.9 (24.4)**	12.7 (16.0)	12.3 (53.2)	18.7 (22.1)	21.2 (41.7)	18.3 (41.1)	52.9 (91.8)	57.7 (90.2)	37.8 (44.4)	28.9 (33.8)	28.8 (37.7)
> 0.25 - 0.42 mm	17.7 (27.3)	26.2 (32.9)	6.9 (29.9)	27.1 (32.0)	10.9 (21.5)	10.0 (22.5)	1.0 (1.7)	3.3 (5.2)	31.2 (36.6)	17.0 (19.9)	18.6 (21.1)
> 0.07 - 0.25 mm	23.0	33.4	2.4	31.6	12.3	10.9	2.0	2.3	15.1	23.3	26.0
> 0.07	8.3 (12.8)	7.3 (9.2)	1.5 (0.06)	7.2 (8.5)	6.4 (12.6)	5.3 (11.9)	1.7 (3.0)	0.7 (1.1)	1.1 (1.3)	16.4 (19.2)	14.6 (16.6)
Percolation Rate (min/in)	5.5	4.0	8.0	5.1	4.7	6.6	9Δ	11Δ	10.5	11.5	9.0

* Results of analyses at the sites of six multiple-home soil absorption systems in Washington.
+ Results of analyses of two separate locations on site.
** Number in parenthesis equals percentage by weight of fine earth (< 2.00 mm diameter).
Δ Percolation rates measured by design engineer, not as part of this study.

Table 11. Estimated Current Hydraulic Loading Rates*.

Parameter	Unit	Harbor Country	Nesika Bay	Tolmie Park	Farwell Estates	Galen Park	Riegel Heights
Design Flow	gpd	16,100	2,437	7,650	3,850	3,850	3,500
Trench Bottom Area	ft^2	6,200	3,600	3,000	1,400	1,140	2,800
Design I.R.+	gpd/ft^2	1.0	0.7	2.6	2.8	3.4	1.2
Current Flow	gpd	7,000**	1,375#	4,260Δ	2,320π	2,360π	1,840π
Current I.R.	gpd/ft^2	0.4	0.4	1.4	1.7	2.0	0.7
Ponding	-	No	Yes	?	No	Yes	No

* For six multiple-home soil absorption systems in Washington.

+ Design infiltration rate (I.R.) in gpd per ft^2 of trench bottom.

** Estimate based upon 56 dwellings x 2.5 persons/dwellings x 50 gpd/person

# Estimate based upon 11 dwellings x 2.5 persons/dwellings x 50 gpd/person

Δ Based on water meter readings. Groundwater infiltration suspected equal to 2 to 3 times the measured water use shown.

π Based upon water meter readings.

Table 12. Mean Septic Tank Effluent Concentrations*.

Parameter	Unit	Harbor Country	Nesika Bay	Tolmie Park+	Farwell Estates	Galen Park	Riegel Heights
BOD_5	mg/L	164	91	46	139	165	87
COD	mg/L	359	231	102	232	341	179
TVS	mg/L	175	144	75	32	72	22
TSS	mg/L	40	34	24	34	102	26
TKN	mg-N/L	49	33	21	25	28	33
NH_4N	mg-N/L	-	-	-	23	25	31
P	mg-P/L	11.1	10.3	5.2	10.4	13.4	11.9
pH	-	6.9-7.1	6.8-7.1	6.4-6.7	-	-	-

* Results of analyses of grab samples (5-6 samples typical) collected between January 20, 1983 and March 15, 1983 at six multiple-home systems in Washington.

+ Groundwater infiltration into the pump chamber was believed responsible for the relatively lower concentrations measured.

PERFORMANCE ASSESSMENT

The performance of the multiple-hove soil absorption systems can only be assessed in regards to infiltration as no purification data (i.e. groundwater quality) were collected.

The occurrence of STE ponding in the wastewater absorption system was utilized as an indirect measure of the infiltrability of the soil system. Excavations were made into five of the six soil absorption systems, in each case at two different locations. Ponding was only observed in two of the systems, Nesika Bay and Galen Park.

The Nesika Bay system had been in operation for approximately 5 years (Table 9). The applied wastewater was typical STE in composition and the bottom area loading rate was estimated to be approximately 2 cm/d (0.4 gpd/ft^2). This rate was less than the 3 to 5 cm/d long-term infiltration rate one might have predicted based on the sand texture of the soil materials at the site. However, a hardpan layer located about 0.6 m (2 ft) below the bottom of this system resulted in perched groundwater and this may have adversely impacted the infiltrative capacity of the system.

The Galen Park system had been in operation for only 2.5 years (Table 9). The applied wastewater contained substantial concentrations of BOD_5 (165 mg/L) and TSS (102 mg/l) and the estimated hydraulic loading rate was approximately 8.1 cm/d (2.0 gpd/ft^2) of trench bottom (Tables 11-12). Despite the very permeable soil materials (Table 10), these loading rates were much higher than commonly recommended rates (U.S. EPA, 1980). The presence of ponding is not surprising, but it is uncertain as to how long the system will continue to function under the present loading conditions before effluent begins to surface or backup.

SECTION 7

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APPENDIX A

Performance Evaluation of the Community Soil Absorption System at Westboro, Wisconsin

MATERIALS AND METHODS

Description of Westboro And Its Wastewater Facility

Westboro is a small rural community located in Taylor County, Wisconsin, adjacent to Silver Creek within the upper Chippewa River drainage basin (Figure A1). In 1976, this community of 205 people had 69 occupied buildings including private residences, a school, four churches and several commercial establishments. All buildings in the community were served by private septic tank systems. A survey by the Wisconsin Department of Natural Resources (DNR) during the mid 1960's revealed that 80 percent of these systems were discharging wastes above ground with many discharging directly into Silver Creek. Consequently, DNR issued an order to the Town of Westboro to upgrade the existing septic tank systems or construct a public wastewater collection and treatment facility.

As a result, the Town Sanitary District No. 1 of the Town of Westboro was formed. Initial facility planning efforts resulted in a recommendation for conventional gravity sewers and two-cell lagoon. The estimated construction costs for this facility were $234,800 in 1967, excluding engineering fees and contingencies. The district residents were unable to afford this facility, so the plan was never implemented. Facility planning efforts were not resumed until the mid 1970's. A variety of conventional and alternative options were investigated by researchers at the University of Wisconsin-Madison and as part of a demonstration grant from the Upper Great Lakes Regional Commission (Otis, 1978). The facilities plan was prepared by Carl C. Crane, Inc. of Madison, Wisconsin (Carl C. Crane, Inc., 1976; Otis and Fey, 1981). The recommended option included a system of small diameter gravity sewers for the conveying the effluent from the existing septic tanks to a community subsurface soil absorption system.

Wastewater pretreatment was accomplished at each building in the community using individual septic tanks. Existing septic tanks were inspected during construction and replaced as needed with prefabricated single-chambered concrete tanks. The tank volume used for individual homes was 1000 gal (3785 L) while for commercial establishments it varied depending upon the type of facility. Four-inch (10 cm) diameter gravity sewers were installed at a minimum gradient of 0.67 percent. Manholes were placed at the upstream end of each line, at junctions and at spacings up to 600 ft (182.9 m). Curvilinear alignments in both the horizontal and vertical planes were employed. Where homes had building drains below the proposed sewer invert, small lift stations following the septic tanks were used. Community lift stations were also necessary at three points in the collection system.

Preliminary site investigations in and around Westboro disclosed the predominant soils to have loam or silt loam surfaces overlying sandy glacial till (Otis, 1978). These soils are deep and well to somewhat poorly drained. On an outwash terrace just west of Silver Creek (Figure 2), deposits of well drained, well graded sand were identified. This location, approximately 25 ft

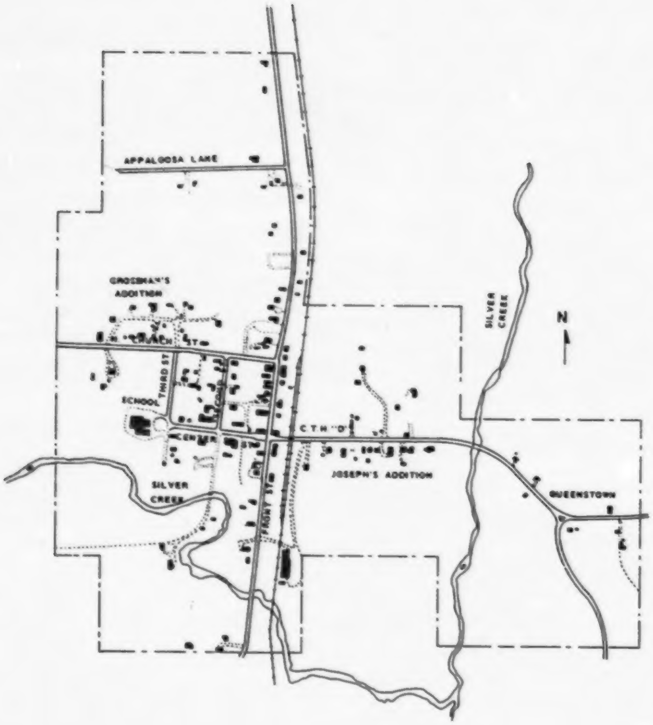
APPALOOSA LANE
GROSSMAN'S ADDITION
CHURCH ST
THIRD ST
SCHOOL
CENTER ST
FRONT ST
C T H "D"
JOSEPH'S ADDITION
SILVER CREEK
SILVER CREEK
QUEENSTOWN
N

Figure A1. Sanitary District #1 of the Town of Westboro, Wisconsin (Otis, 1978).

(7.6m) above the stream elevation, was selected as the site for construction of a network of large soil absorption beds.

The wastewater application rate chosen for the absorption beds was based upon site soil characteristics. Soil borings characterized the subsurface soils as sand and loamy sand textures. An application rate of 1.2 qpd/ft^2 (5 cm/d) was selected based on work with individual systems (Bouma, 1975). The design flow, based upon 250 qpd (0.9 m^3/d) per home, was projected to be 30,000 qpd (113.6 m^3/d). The necessary infiltration area of 25,000 ft^2 (2322 M^2) was provided in three, 100 ft (30.5 m) by 130 ft (39.6 m) beds (Figure A2). Each bed was designed to handle 15,000 gal/d so that at any one time, two of the beds could handle the design flow with the third acting as a standby. Annually, the standby bed was to be rotated into service so that each bed would receive wastewater for two years and then rest for one year. The resting period was intended to restore the bed's infiltrative capacity through drainage, aeration and biochemical oxidation of the clogging zone.

Pressure distribution networks were designed to distribute septic tank effluent (STE) uniformly over the infiltrative surface of each bed (Figure A2). Two manifolds, 8-inch (30 cm) telescoping down to 4-inch (10 cm) diameter were used to feed 4-inch (10 cm) laterals spaced every 5.25 ft (1.6 m). The inverts of the laterals were perforated with 15/32 inch (1.2 cm) holes located at 6.5 ft (1.9 m) spacings. STE was delivered to each bed by a separate 12-inch (30 cm) diameter force main served by a 10-inch siphon, capable of discharging an average of 1000 gpm (3.8 m^3/m) at the design head (Figure A3). Two siphons were to be in service at any time, automatically alternating operation and discharging approximately 8,000 gal per cycle. At design capacity, each bed was to receive 2 doses per day. The siphon serving the resting bed could be deactivated by closing a ball valve installed in the siphon's blow-off vent.

Construction began in April, 1977 and was completed in September, 1977. The construction costs are delineated in Table A1. Construction funding was provided through financial assistance from the Farmer's Home Administration and the Wisconsin DNR as well as local assessments and hook-up charges. At least a 12 percent savings in construction costs was realized compared to conventional sewerage. Moreover, the facility reduced operating costs over conventional gravity sewers and a stabilization pond facility by 65 percent (Otis and Fey, 1981). User charges for each residence during 1981 were only $10.00/month.

The facility has been in operation since the Fall of 1977. The Westboro Sanitary District has been responsible for the operation and maintenance of all components of the system beginning at the inlet to each septic tank. The facility was designed to require very little attention. All duties are performed by a local operator in an average of 2 to 4 hours per week. The proposed facility maintenance schedule is shown in Table A2.

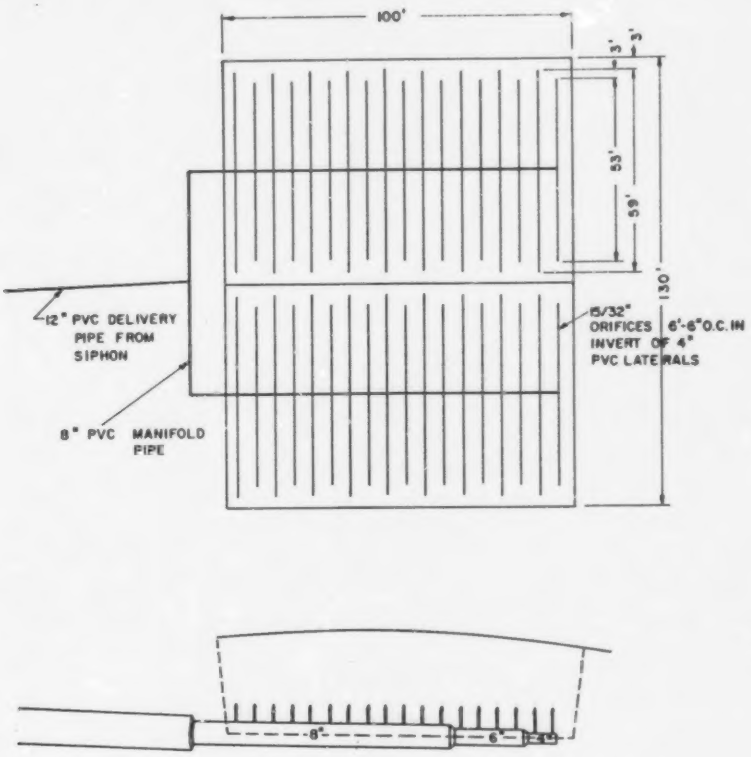
100'
3'
3'
53'
59'
130'
12" PVC DELIVERY PIPE FROM SIPHON
8" PVC MANIFOLD PIPE
15/32" ORIFICES 6'-6"O.C. IN INVERT OF 4" PVC LATERALS
8"
6"
4"

Figure A2. Pressure Distribution System Schematic (Otis, 1978).

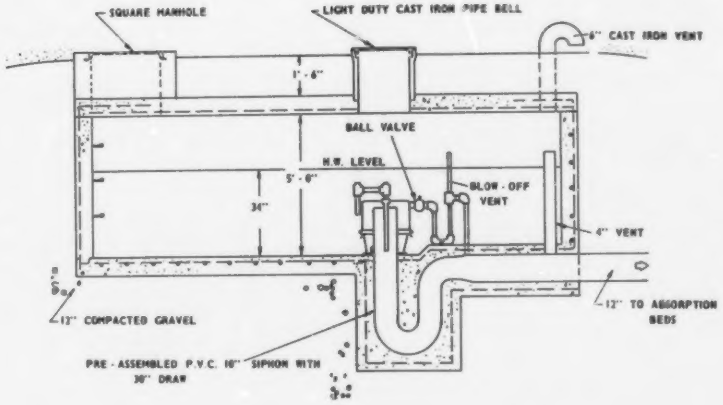
SQUARE MANHOLE
LIGHT DUTY CAST IRON PIPE BELL
6" CAST IRON VENT
1'-6"
BALL VALVE
H.W. LEVEL
5'-0"
34"
BLOW-OFF VENT
4" VENT
12" COMPACTED GRAVEL
12" TO ABSORPTION BEDS
PRE-ASSEMBLED P.V.C. 10" SIPHON WITH 30" DRAW

Figure A3. Profile Schematic of the Siphon Chamber at Westboro (Otis, 1978).

Table A1. Westboro Construction Cost Summary (Otis and Fey, 1981).

Component	Item	Cost (1977 Dollars)
Collection (House lateral, septic tanks, sewers and lift station)	Construction	$252,635
	Land and Rights	0
	Legal Services	4,500
	Engineering and Inspection	48,325
	Bond Council	1,000
	Subtotal	$306,460
Treatment (Siphon chamber and soil absorption fields)	Construction	98,865
	Land Rights	6,000
	Legal Services	2,500
	Engineering and Inspection	20,750
	Bond Council	600
	Subtotal	$128,715
	Total	$435,175

Table A2. Facility Maintenance Schedule (Otis and Fey, 1981).

Daily

- Check lift station alarm lights.

Weekly

- Open lift stations for visual inspection of pump operation float, control operation and debris accumulation.
- Record total weekly flow from pump running time meters as per WPDES* permit requirement

Monthly

- Check siphon operation.
- Inspect observation vents in each bed for depth of ponded water; switch cells if necessary.

Annually

- Each spring, alternate resting bed into service and drain manifold of bed taken out of service.
- Inspect the surface of the absorption field and fill any holes and depressions.
- Pump 1/3 of septic tanks each year according to schedule.
- Pump lift stations and siphon chamber to remove sludge.
- Flush sewer lines as necessary.

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* Wisconsin Pollution Discharge Elimination System.

Review of Previous Monitoring Efforts

Monitoring at Westboro was initiated prior to construction of the wastewater facilities in 1977 and during their first year of operation. The monitoring was performed by staff from the University of Wisconsin-Madison with funds provided by the Upper Great Lakes Regional Commission. Detailed information may be found elsewhere and only a brief summary follows (Otis, 1978).

Water use was metered in 25 homes and businesses between April, 1977 and November, 1978, to determine average daily flows and identify any increase in water use after the public facility became operational. Based upon monthly water meter readings, the average residential flow measured at 21 homes ranged from 25 to 546 gal/d (94.6 to 2067 Lpd) while the average for all homes combined was 169 gal/d (640 Lpd.) The average number of occupants was 4.7 persons and per capita usage averaged only 36 gpcd (136.3 Lpcd), with a range of 8 to 71 gpcd (30.3 to 269 Lpcd). No change in water use occurred as a result of the new wastewater facilities (Otis, 1978).

The average daily wastewater flow was determined from elapsed time meters on the pumps in the main lift station and the measured discharge rate of the pumps. The average daily flow determined between February and October, 1978 was 7,345 gal/d (27.8 m^3/d) (Otis, 1978). With two beds in service, this daily flow represented only 25 percent of the design flow.

Groundwater observation wells were installed in and around the soil absorption beds to determine the response of the groundwater to the percolating wastewater. In June, 1977, 28 observation wells were installed prior to the facility becoming operational. Subsequently, certain of these wells were abandoned due to well screen clogging or other problems. Additional wells were installed in close proximaty to the wastewater absorption beds to facilitate the assessment of any groundwater impacts. As of September, 1979, 27 wells were installed at 16 locations around the site with nests of two to three wells at different depths at eight of the locations (see Figure 3). Each well consisted of lengths of 1 1/4-inch (3.2 cm) diameter plastic pipe with a 3 ft (91.4 cm) slotted well point. They were set in an augered 4½-inch (11.4 cm) diameter hole and then backfilled with natural soil materials. A chalked tape and hand bailer were used initially to measure water potentials and to evacuate the wells prior to sampling. Due to the potential for well contamination and the difficulty in monitoring during the winter, a new well head was designed. The new head utilized compressed air from a hand tire pump to enable measurement of water potentials using a bubbler tube and to evacuate the wells for sampling.

Observed groundwater elevations prior to any wastewater loading revealed the groundwater was at least four feet (1.2 m) below the bottom of the absorption beds and the flow was both downward and southeasterly towards Silver Creek. Groundwater samples collected during the first year of operation were analyzed for total solids, nitrogen forms, total phosphorus, chloride, calcium, magnesium, total and fecal coliforms and fecal streptococcus. Compared to a single sampling prior to startup of the facility, water quality changes were only noted at well 13-3 (Otis, 1978). This well extracted water from approximately 15 ft (4.6 m) below the wastewater infiltrative surface and 40 ft (12.2 m) down slope from the southeast edge of bed 3 (Figure 3). Water samples from this well exhibited an increase in total nitrogen concentrations from less then 0.5 mg-N/L to over 15 mg-N/L. Soon after the beds began receiving wastewater, the increase in nitrogen was in the form of nitrate, but later changed to ammonium while the total nitrogen remained constant.

Water quality sampling in Silver Creek began in July, 1975. To measure stream flows, a gaging station was established at the CTH D bridge just downstream of the absorption beds (Figure 2 and A1). The result of analyses of stream samples collected upstream and downstream of the wastewater absorption beds revealed no effects on stream water quality.

Monitoring Procedures of This Study

Soil and Site Characteristics--

Soil and site conditions were investigated in this study during October, 1981. Based upon operational and monitoring data available at that time, questions had arisen as to the siting of the absorption beds, the wastewater loading rate, and soil conditions affecting the system's performance. Detailed soil evaluations included the inspection of soil profiles from seven backhoe pits located around the perimeter of the absorption beds (B1-B7) in addition to hand borings (B8-B10) (Figure 3). The profiles were described in detail, substantially according to the method of SCS (1981) and the Wisconsin Administrative Code (1980). Particular attention was directed to morphologic features which might impact wastewater absorption and treatment. Soil samples were collected from selected representative horizon's of some pits. Particle size analysis of the samples was conducted according to the methods of Day (1965).

Three percolation tests (P1-P3) were conducted along a north-south transect just east of Bed 1 where fine materials (vfs-si) were apparent in adjacent pits B1-B2. These tests conducted according to the method prescribed by Wisconsin Adm. Code (1980), provided some estimate of percolation rates in the more hydraulically restrictive materials of the site. Saturated hydraulic conductivity was determined for re-packed grab samples (maximum dry density) of selected soil horizons using concentric-ring permeaters (CRP's) (Hargett, 1982).

Applied Wastewater Characteristics--

The hydraulic loading to the absorption system was monitored using a float-operated mechanical counter installed in the siphon chamber. Each time wastewater was discharged from the siphon chamber, the counter recorded the event. The counter was read periodically and the average number of applications per day determined. These data, coupled with the known volume of wastewater per siphon discharge cycle, were used to calculate the average hydraulic loading per day. Grab samples of septic tank effluent were periodically collected from the siphon chamber. Analyses were performed according to U.S. EPA approved procedures for biochemical oxygen demand, chemical oxygen demand, solids, nitrogen forms, phosphorus, chlorides, conductivity, total and fecal coliforms and fecal streptococci.

Soil Infiltrability--

Ponding of the applied septic tank effluent above the bottom infiltrative surface of each operating bed was utilized as an indirect measure of the soil infiltrability. Ponding depths were monitored through existing observation ports installed during construction of the facility in 1977 (Otis, 1978). The 4-in (10 cm) diameter ports were placed with the bottoms resting on the infiltrative surface and the top extending several feet above the final ground surface and topped with a vent cap. The bottom section of each observation port was perforated to allow the free movement of septic tank effluent in and out of the port. At least three observation ports in each bed were inspected periodically to determine the depth of ponding, if any.

Subsystem Soil Moisture and Gas Characteristics--

As part of this project, monitoring instruments were installed at four locations within or near Bed 2: 20 ft (5.1 m) outside the west edge, near the center, at the east edge and 20 ft (5.1 m) outside the east edge (Figure 3, A4; Points D, A, B, C). These instruments included groundwater observation wells as well as soil moisture tensiometers and gas samplers at approximately 12 inches (30.5 cm) and 30 inches (76.2 cm) below the bottom of Bed 2 (Table A3).

The groundwater observation wells consisted of lengths of 1 1/4-inch (3.2 cm) diameter plastic pipe with a 3 ft (91.4 cm) slotted well screen. The groundwater level in each well was measured periodically using a sounding device (popper) attached to a fiberglass measuring tape.

The soil moisture tensiometers were constructed of 7/8 inch (2.2 cm) outside diameter (o.d.) porous ceramic cups (Soil Moisture Equipment Corp., Santa Barbara, CA., Model 2600A) attached to the bottom of a length of clear acrylic tubing. Nylon tubing with 1/8 inch (3.2 mm) o.d. was used as the lead conduit from the tensiometer to a mercury manometer. Manometers were assembled adjacent to the instrument location early on the day that measurements were to be made. After tensiometer equilibration, several

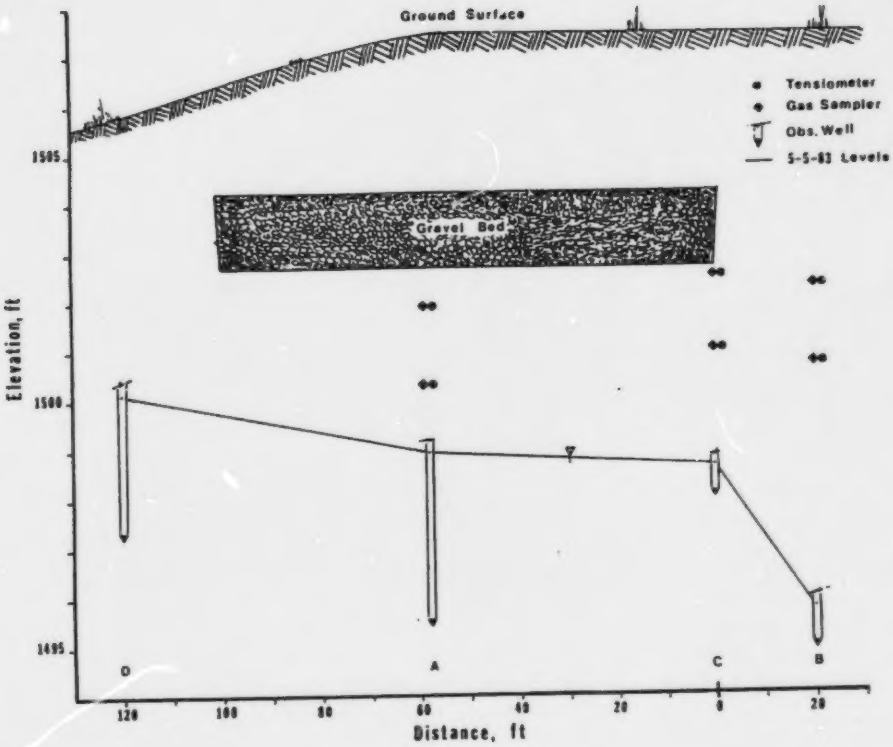

Ground Surface
Tensiometer
Gas Sampler
Obs. Well
5-5-83 Levels
Gravel Bed
Elevation, ft
1505
1500
1495
D
A
C
B
120
100
80
60
40
20
0
20
Distance, ft

Figure A4. Subsurface Monitoring Instruments Under and Beside Bed 2 (Note: Exaggerated Vertical Scale).

Table A3. Elevations of Subsystem Monitoring Instruments at Bed 2.

Placement Location*	Instrument	Ground Surface (ft)	Infiltrative Surface (ft)	Instrument Bottom (ft)
A	Groundwater Observation Well	1507.5	1502.8	1495.4
	Tensiometer 1			1501.9
	Tensiometer 2			1500.3
	Gas Sampler 1			1501.9
	Gas Sampler 2			1500.4
C	Groundwater Observation Well	1507.4	1502.8	1498.0
	Tensiometer 1			1502.5
	Tensiometer 2			1501.0
	Gas Sampler 1			1502.5
	Gas Sampler 2			1501.0
B	Groundwater Observation Well	1507.4	1503.5**	1494.9
	Tensiometer 1			1502.3
	Tensiometer 2			1500.7
	Gas Sampler 1			1502.3
	Gas Sampler 2			1500.7
D	Groundwater Observation Well	1505.8	-	1497.2

Note: m = 3.28 x ft.

* Refer to Figures 3 and A4 for locations.

** Point B is outside Bed 2 so there is no infiltrative surface. Elevation shown is for depth of excavation prior to placement of instruments.

measurements were made to assure instrument stability. The manometers were disassembled between measurements. Further details regarding procedures for the measurement of soil moisture potential may be found in Richards (1965) and Bouma, et. al. (1974).

Soil pore gas samples were obtained using equilibrium diffusion chamber samplers similar to the bottomless chamber type described by Smith (1977a). These samplers consisted of 1-inch (2.5 cm) i.d. plastic pipe with an air-tight end piece through which a glass capillary protruded on the access end. The gas reservoir end of the sampler was recessed to provide a 24-cc volume of soil atmosphere in continuity with the adjacent soil and sampleable via the glass capillary. The access end of the capillary was capped with an air-tight rubber septum through which gas samples were collected using 1-cc (0.16 inch^3) disposable nylon syringes with 27 ga. needles. The volume of the glass capillary was first evacuated and discarded and then three sequential 1-cc samples were collected from each instrument and labled. Immediately upon sampling, the needle syringe assembly was stuck into a rubber stopper and completely immersed in oil for transport stability. Gas samples were analyzed within 24 hours on a gas chromatograph (Fisher Model 1200), equipped with dual columns and dual thermal detectors. A strip-chart recorder was used to record chromatographic response. A standard gas mixture was used as a reference to determine the percent composition of N_2, O_2, CO_2 and CH_4 in each sample.

Installation of monitoring instruments within Bed 2 was accomplished as follows (refer to Figure 3 and A4). THe soil material over the absorption bed was excavated and as the gravel was removed, a galvanized metal cylinder (o.6 m diam.) was pressed into the soil infiltrative surface. Any septic tank effluent within the interior of the cylinder was then removed using a hand-operated diaphragm pump. A 3-inch (7.6 cm) diameter bucket auger was used to excavate three separate holes: one for a groundwater observation well; a second for a tensiometer and gas sampler at 12 in. (30.5 cm) depth; and a third for a tensiometer and gas sampler at 30 in. (76.2 cm) depth (Table A3). After instrument placement, the holes were backfilled with natural materials and a layer of bentonite. The metal cylinders were then perforated to allow septic tank effluent to pond over the location of the instruments. To facilitate access to the instruments for servicing and measurements, the large metal cylinder was extended up to the ground surface.

Groundwater Characteristics--

The groundwater at the site was characterized using 27 existing monitoring wells (Otis, 1978). These included wells at 16 locations around the site with nests of two to three wells at different depths at seven of the locations (Figure 3, Table A4). Each well had been previously outfitted with a specially designed pneumatic appartus that enabled the measurement of groundwater potentials and the collection of water samples (Figure A5; Otis, 1978).

Table A4. Elevations of Groundwater Monitoring Wells.

Monitoring Well Location*	Monitoring Well Point	Surface Elev. (ft)	Well Depth** (ft)	Well Bottom Elev. (ft)	Bubble Tube Bottom Elev. (ft)
1	1	1503.5	34.4	1469.1	1471.0
	2	"	12.0	1491.5	1492.0
	3	"	8.6	1494.9	1495.9
2	1	1505.2	35.0	1470.2	1472.5
	2	"	22.8	1482.4	1483.3
	3	"	15.1	1490.1	1491.0
3	1	1503.6	11.5	1492.1	1492.5
4	1	1504.6	21.9	1482.7	1483.8
	2	"	12.4	1492.2	1493.1
5	1	1497.4	21.6	1475.8	1477.6
	2	"	11.7	1485.7	1488.7
11	1	1483.1	9.7	1473.4	1476.3
12	1	1497.7	17.6	1480.1	1480.4
13	1	1503.1	37.5	1465.6	1469.2
	2	"	26.7	1476.4	1477.5
	3	"	16.5	1486.6	1489.0
14	1	1506.6	44.7	1461.9	1467.9
	2	"	31.1	1475.5	1476.5
	3	"	19.1	1487.5	1490.5
15	1	1502.8	27.0	1475.7	1477.4
	2	"	16.8	1486.0	1488.2
17	1	1507.6	15.7	1491.9	1492.1
18	1	1506.2	17.4	1488.9	1489.3
19	1	1507.4	15.6	1491.9	1494.9
20	1	1507.4	18.9	1488.5	1489.1
21	1	1505.3	14.3	1490.9	1494.4
22	1	1507.3	17.5	1489.8	1490.7

* Refer to Figure 3 for locations.

** Distance from ground surface to bottom of well screen.

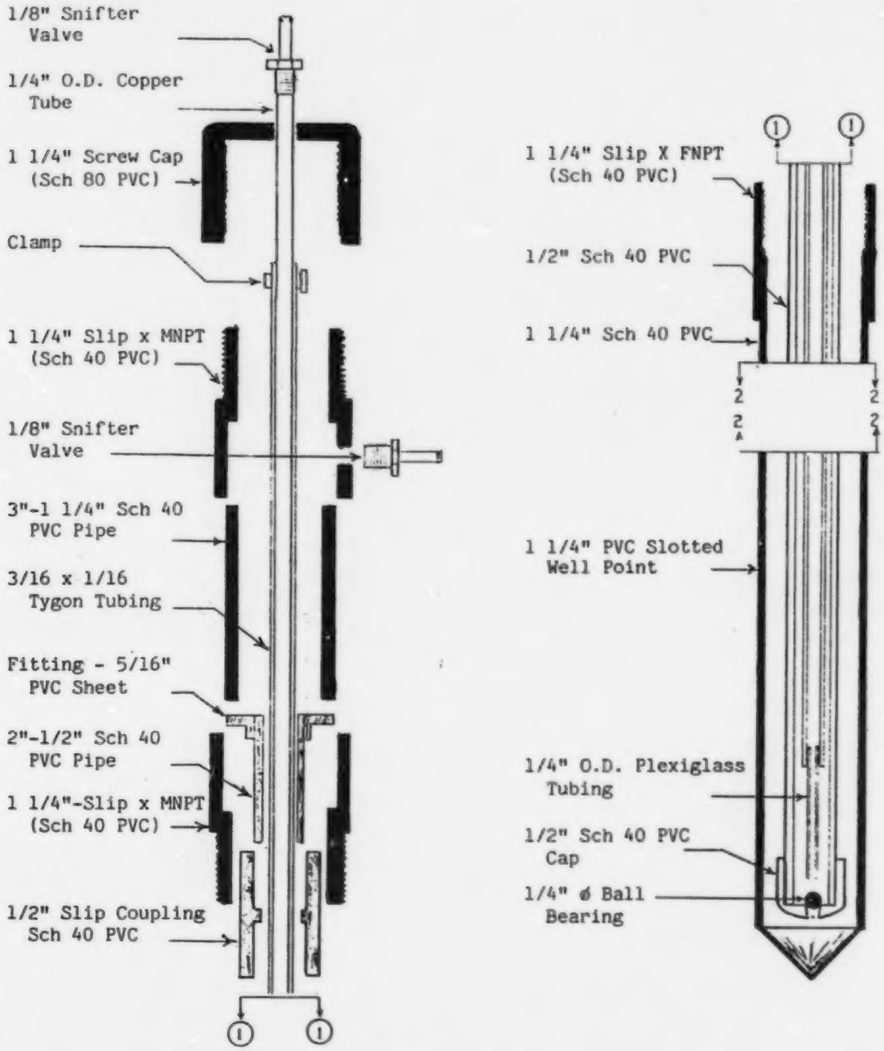

1/8" Snifter Valve
1/4" O.D. Copper Tube
1 1/4" Screw Cap (Sch 80 PVC)
Clamp
1 1/4" Slip x MNPT (Sch 40 PVC)
1/8" Snifter Valve
3"-1 1/4" Sch 40 PVC Pipe
3/16 x 1/16 Tygon Tubing
Fitting - 5/16" PVC Sheet
2"-1/2" Sch 40 PVC Pipe
1 1/4"-Slip x MNPT (Sch 40 PVC)
1/2" Slip Coupling Sch 40 PVC
①
①
①
①
1 1/4" Slip X FNPT (Sch 40 PVC)
1/2" Sch 40 PVC
1 1/4" Sch 40 PVC
2
2
2
2
1 1/4" PVC Slotted Well Point
1/4" O.D. Plexiglass Tubing
1/2" Sch 40 PVC Cap
1/4" ø Ball Bearing

Figure A5. Well Monitoring Apparatus (Otis, R. Unpublished Drawings).

The following procedures were used to measure groundwater potentials and collect samples during each site visit. During the first day of a site visit, any groundwater within each well was evacuated. The wells were then allowed to recover for approximately 18 to 24 hrs. After this recovery period, groundwater samples were collected. First, approximately 100 mL of groundwater were discarded. Then a 500 to 1000 mL sample was collected in two, polyethylene bottles. One sample volume was preserved with concentrated sulfuric acid. These two samples were subsequently analyzed for chemical/physical parameters. Subsequently, a 100 to 200 ml sample was collected in each of two sterile, plastic bags for subsequent analyses for microbiological parameters. All samples were refrigerated during transport back to Madison, Wisconsin where analyses were performed by a private testing lab according to U.S. EPA approved procedures for total dissolved solids, nitrogen forms, phosphorus, chlorides, conductivity, fecal coliforms and fecal streptococci.

The groundwater data collected in this study were analyzed by several means. Routine statistical methods and hand contour plotting techniques were initially used. Further analyses were performed using a computer statistical analysis program known as multi-dimensional spline smoothing in conjunction with a contour plotting routine. Details of the theory of this method can be found in Wendelberger, 1981 and MACC, 1981, while the application of this technique to groundwater monitoring has been described by Fine, 1983. Briefly, multi-dimensional spline smoothing consists of using a laplacian smoothing spline to model a smooth but otherwise unknown function. The method of generalized cross validation is used to choose and optimize the smoothing parameter. Use of this model for groundwater applications assumes a relatively smooth groundwater surface with no sharp peaks and one that can be expressed by some function, in this case, Darcy's Law.

Surface Water Characteristics--

The flow volume of Silver Creek, a stream adjacent to the soil absorption beds, was determined periodically via a gaging station located just downstream of the soil absorption beds. Grab samples were collected from the stream, both upstream and downsteam of the soil absorption beds and handled and analyzed the same as for the groundwater samples (Figure 3).

Analytical Quality Control--

To insure quality control of analytical laboratory procedures approximately 10 percent of the samples collected in the field were split with one fraction of each submitted to the laboratory as an unknown. Blank and spiked samples were prepared and analyzed by laboratory personnel along with each round of field samples. In addition, U.S. EPA reference samples were analyzed periodically.

Operation and Maintenance--

The operation and maintenance history of the wastewater facilities was investigated. Of concern was the period between system start up in the Fall of 1977 and the beginning of this study in June of 1981. Information was gathered from published reports (Otis, 1978) and conversations with the Town of Westboro Sanitary District commissioners and facility operator.

RESULTS AND DISCUSSION

Soil and Site Characteristics

General Description --

The wastewater absorption beds at Westboro are located on a glacial outwash terrace adjacent to Silver Creek (Figure 3). The site of the beds is nearly level, at an elevation of 457 - 461 m (1500 - 1510 ft). The landscape surrounding the system includes agricultural fields sloping toward it from the north and undeveloped fields sloping gently to Silver Creek 75 m east, and a drainage ditch 30 m south which feeds into the creek. The soils of this setting formed in 0.5 - 1.0 m or less of silty loess overlying loose sandy and gravelly outwash. Soils of the Antigo, Brill, (both Typic Glossoboralfs, fine-silty over sandy or sandy skeletal, mixed frigid) Poskin (Aquic Glossoboralf, same family) and Onamia (Typic Eutroboralf, fine-loamy over sandy or sandy skeletal, mixed, frigid) association typify this landscape position and geologic setting (SCS, 1966; Hole, 1976).

Thin bands of finer textured fluvial deposits are commonly interbedded in the sand and gravel. This banding may be locally more dominant in some profiles or absent in other profiles. Because of the highly variable depositional environment, soil profiles may vary markedly over a short distance, especially in sections perpendicular to the general drainage.

The glacio-fluvial deposits vary in depth, with the underlying glacial till generally at an elevation below 445 m (1460 ft) (Weber and Lawson, 1972). This Wisconsin Age till is typically sandy loam to loam and may be gravelly or cobbly. Precambrian granite bedrock underlies the till at approximately 425 to 430 m elevation (30-37 m depth).

Review of Pre-Construction Site Evaluation --

The site was evaluated for its suitability for wastewater absorption during the summer of 1976. Staff of Carl C. Crane, Inc., of Madison, Wisconsin and the Small Scale Waste Management Project at the University of Wisconsin-Madison were involved. The evaluation included examination of soil morphology and horizonation from numerous borings and open pits, and estimation of saturated hydraulic conductivity based upon morphology and percolation tests. The results of this evaluation as determined from personal communication (Otis, 1983; Fey, 1983) and previous publications (Otis, 1978) were reviewed as part of this study.

The soil profiles observed in pits B11-15 (Figure 3) were reported as dominantly very sandy in texture with considerable fines (silts) in some strata. Groundwater was observed at 1.8 m (72 in.) in pits B11 and B12 although no soil mottling was associated. Shallow, seasonally perched conditions, above very silty horizons, were reported for areas to the west of the proposed system. The saturated conditions observed in pits B11 and B12 may also have been due to perched water above flow-restricting horizons.

Elsewhere on the site groundwater was estimated at depths greater than 2.4 m (96 in.).

Saturated hydraulic conductivities (K_{sat}) were estimated based upon soil morphology to be of the order of 100 cm/d for fine sands to 400 cm/d or more for medium and coarse sands. Silt loam to silty clay loam materials perching groundwater in the area west of the absorption bed site were estimated to have Ksat values of 2 to 20 cm/d. Percolation tests conducted on the site (P4-P6, Figure 3) at a depth of 1.07 m (42 in.) yielded values greater than 200 cm/d (2 min/in) (see Table 2).

Based upon the groundwater conditions, finer textures and interbedding observed in the area of borings B11 and B12 and west thereof, this area was rejected as a suitable site for the system. The preferred area was located along a transect from southwest to northeast, parallel to Silver Creek and centered along the terrace. The soils in this area were judged to be more uniformly sandy and permeable with greater depth to groundwater. Given these site conditions, an installation depth for the infiltrative surface of the system was chosen to be 1.07 m (42 in.).

Unfortunately, the entire preferred area for locating the system was not available and Bed 1 had to be constructed further west and in finer soils than desired. During excavation of the beds, very silty deposits were encountered in the northwestern one-third of Bed 1. These very well sorted materials (very fine sands and silt) were about 1.5 m (60 in.) thick at their deepest point and were perching shallow groundwater. This material was removed exposing very permeable coarse sands, and local sandy fill was put in its place. After excavation of the vertically restrictive finer material, the laterally flowing groundwater readily infiltrated into the sandy strata below.

The absorption beds were sized based upon a maximum design infiltration rate of 5 cm/d (1.2 gpd/ft^2) for sandy soils with percolation rates less than 10 min/in. (Bouma, 1975). This application rate seems in retrospect, very reasonable considering the soil conditions and percolation rates reported, and the state of knowledge available at the time (i.e. 1976).

Review of Groundwater Monitoring Well Logs --

During the summer and fall of 1977, groundwater monitoring wells (nests 1-16) were installed across the site (Figure 3). General descriptive logs were prepared and Karnauskas and Eisen (1977) developed a report regarding the hydrogeological conditions at the site. Soil samples (hollow stem auger cuttings) of selected strata were sieved and permeabilities were estimated according to the methods of Masch and Denny (1966). The sands, mostly medium (0.25-0.50 mm) were estimated to have a mean permeability of 1330 cm/d (325 gpd/ft^2) with a range of 370 to 3890 cm/d (90 to 950 gpd/ft^2).

Additional wells were installed during Summer 1979 (Wells 17-22, Figure 3). Descriptive logs provided limited information on the homogenized cuttings of finely interbedded strata extracted from flights of a hollow-stem augar. Descriptions were very imprecise in textural character and depth of origin.

It is important to note that the clayey materials described in some logs were listed at depths generally greater than 6 m (20 ft), deeper than the background water table. It was believed that these materials would not impact the site hydrogeology, at least for the purpose of this study.

Detailed Soil Description --

Detailed descriptions of soil pits B1-B7 were prepared as part of this study (Figure 3). The soil descriptions evidence considerable variability across the site, especially from north to south. Pit B2 represents a rather finely interbedded soil profile, with several abrupt textural breaks judged capable of impeding vertical water movement. The stratum at 137 to 155 cm (54-61 in.) in Pit B2 was exemplary of very well sorted, very fine sands and silts which effectively perched water in coarser sandy horizons above. Considerable free water was observed skirting through the overlying sandy zone, down the side of the pit and into the coarse sands below. Most of the strata underlying the site appeared to dip roughly 5 to 20 degrees toward the south-southeast.

These interbedded materials are characteristic of inwash-outwash deposits which are alternately subjected to high and low energy depositional environments, resulting a wide range of sediments. The lateral continuity of finer textured deposits in these strata was highly variable, although in some cases it was extensive enough to intercept vertical flow and confine it to more permeable layers.

Although no continuous free standing water was observed in pits B1-B3 located east of Beds 1 and 2, soil mottling was observed as shallow as 25 to 46 cm (10-18 in.) in each pit. This indicated some possible seasonal saturation or near saturation conditions (Vepraskas, 1974). In each case, the same horizon displayed platy (horizontally oriented) structure, likely somewhat resistant to vertical water movement. In pits B1 and B2, the strata underlying the zones was quite mottled, interbedded and varied in texture.

To the south, the pits revealed soils much coarser in general texture with fewer and thicker layers. Pit B3 was transitional to the more dominant sands and gravels found in pits B4 and B5 adjacent to Bed 3. However, even in the B4 and B5 profiles, some bands or stringers of silts and very fine sands very found which were similar to the thicker zones found in Pit B2.

Pit B6, west of Best 1 and opposite of Pit B1, displayed interbedded sands, gravels and silt strata with free water, possibly perched, standing at 180 cm (70 in.). Pit B7 showed similar conditions both with a thick zone of well-sorted silts and very fine sands at 117 to 168 cm (46-66 in.), and standing water at 168 cm. Both B6 and B7 were highly mottled below a depth of 25 cm (10 in.).

Particle Size Distribution --

Particle size distribution data for selected representative soil horizons are presented in Table A5. Five of the eight samples analyzed were classified as sands (USDA), two as sandy loams and one as loam. Three of the five sands qualified as fine sands and had fine plus very fine sand contents of 57 to 76 percent. Seven of the samples had more than 64 percent sand and six had more than 66 percent material finer than medium sand (0.25 mm). The three "loamy" samples are deposits of very well sorted and densely packed particles of the silt to very fine sand size. In these three samples the summation percentage of silt plus very fine sand ranged from 71 to 77 percent. These same deposits were observed to very effectively impeded vertical water movement in soils pits B1-B3 and B6-B7.

Percolation Rates --

The results of percolation tests performed as part of this study are shown in Table 2 along with those conducted prior to construction of the wastewater absorption beds. The percolation rates measured in this study (P1-P3) were for soils in the less permeable and somewhat impermeable strata east of Bed 1. Rates ranging from 140 to 470 cm/d (25 to 8 min/in) were determined. Percolation rate measured prior to construction were in excess of 2150 cm/d (≤2 min/in).

The soil materials at the installation depth of 1.07 m (42 in.) in Pits B1 and B2 (near P1-P3), contained some sandy strata inter-layers with finer horizons. Because of the likelihood of considerable horizontal flow in these materials, the percolation test procedure would be a very poor indicator of the vertical permeability required of large, rectangular absorption beds.

Saturated Conductivity --

Table 3 presents the results of saturated hydraulic conductivity (K_{sat}) measurements conducted on selected samples. These samples were judged to represent the most hydraulically restrictive materials encountered (Pit B2, loam horizon at 81-91 cm depth) and the typical fine sand material (Pit B2, 112-125 cm and 163-203 cm depth). The loam sample (Pit B2) displayed a K_{sat} of 9.5 cm/d while a very sandy loam sample had a K_{sat} of 86 cm/d. The two fine sand samples resulted in K_{sat} values of 366 and 247 cm/d.

Discussion of Soil and Site Characteristics --

The 1976 pre-construction site investigations were carried out in accordance with Wisconsin Adm. Code (WAC H62.20, 1972) and Department of Health and Social Services policies. Numerous soil borings and pits were described and percolation tests were conducted according to Code requirements. Less desirable soil areas were delineated through these evaluations, although some of these areas had to be used for construction. Elsewhere, the site soil conditions were properly judged, based on the criteria used and data available, to be well-suited for installation of a network of large soil absorption beds.

Table A5. Particle Size Distribution of Soil Samples.

Boring No.*	Depth	Percent of Fine Earth (Mass %)									USDA Texture	Unified Texture	% Whole Soil Gravel
		Total			Sand Fractions **								
		Sand	Silt	Clay	vcs	cs	ms	fs	vfs	≤fs ***			
B1	52-62 in (132-157 cm)	64.1	30.1	5.8	0.3	0.0	0.1	19.4	44.2	99.6	vfsl	SM	0.0
B2	32-36 (81-91)	41.4	44.3	14.3	0.1	0.5	1.8	11.1	27.8	97.6	l	ML	0.1
B2	44-49 (112-124)	95.5	2.5	2.0	0.2	0.2	19.3	68.7	7.2	80.4	fs	SP	0.3
B2	64-80 (163-203)	90.8	7.3	1.9	4.4	7.0	21.7	43.8	13.9	66.9	fs	SP	2.0
B3	40-76 (102-193)	96.7	2.0	1.3	8.1	16.2	42.2	26.8	3.4	33.5	s	SP	16.8
B4	16-42 (41-107)	90.9	6.3	2.8	3.6	5.7	23.5	47.9	9.6	67.3	fs	SP	3.9
B4	42-54 (107-137)	97.6	1.0	1.4	18.9	26.9	34.6	15.1	2.1	19.6	cs	GP	61.9
B7	46-64 (117-163)	65.3	33.9	0.8	0.0	0.2	0.5	21.1	43.5	99.2	vfsl	SM	0.0

* Refer to Figure 3 for boring locations.

** vcs = very coarse sand (1.0-2.0 mm)
cs = coarse sand (0.50-1.0 mm)
ms = medium sand (0.25-0.50 mm)
fs = fine sand (0.10-0.25 mm)
vfs = very fine sand (0.05-0.10 mm)

*** Percent of fine earth with a particle diameter equal to or smaller than fine sand (0.10-0.25 mm)

Based on soil conditions and percolation tests, a design loading rate of 5 cm/d (1.2 gpd/ft^2) was applied.

A more rigorous re-evaluation of soil conditions at the site revealed considerable additional information regarding site and soil suitability. A detailed assessment of backhoe pits spaced around the system beds showed that the soils across the absorption bed area are highly variable vertically and laterally and certainly more complex than previously thought. In fact, the stratigraphy of the area was too complex to be accurately traceable, beyond speculation, for even 30 m (100 ft).

Moreover, the north one-third to one-half of the site contained a solum of highly interbedded very fine sands and silts with truncating layers of coarser sands and gravels. These very fine sandy loams, loams, and silt loams contained highly uniform particles, mostly in the 0.02 to 0.20 mm size range. These materials were often compact and very resistant to vertical flow as observed in the field. Laboratory measurement of saturated hydraulic conductivity confirmed their low permeabilities with K_{sat} less than 10 cm/d. By contrast, the medium to coarse sands and gravels likely have K_{sat} values of 500-1000+ cm/d.

The soils to the south half of the installation were distinctively more sandy and less bedded. Although some stringers or bands of fines (vfs-si) existed, they appeared to be thin and possibly discontinuous. Vertical permeabilities of these materials were likely much greater than those of the north area, due to the vertical continuity of the coarser materials.

The 1976 percolation tests, P4-P6, were confined to soils in the area of the south bed. Thus, the very rapid rates observed would be expected, given the soil materials present. The 1981 percolation tests, P1-P3, were intentionally placed in a more hydraulically restrictive soil profile and produced slower rates (Table 2). However, the rates measured likely reflect horizontal permeability and not the vertical permeability of the restrictive horizon(s). By example, the slowest percolation rate measured was 145 cm/d (25 min/in) compared to the 10 cm/d K_{sat} measured by the CRP technique in the finer soil present (Tables 2 and 3). Thus, the percolation test is clearly a very faulty method upon which to site and size a system, especially in soil conditions such as those present in the north half of the site.

If the system area were considered for subsurface wastewater absorption under current State policies or generally accepted site evaluation practices (U.S. EPA, 1980), the northern half might not be found suitable due to soil mottling, characteristic of seasonal saturation. However, based on the textural character of the profile (in general sands and sandy loams) and loading rate similar to that used previously. By comparison, the south half of the site would very likely be judged as excellent considering the medium or coarser sandy conditions. Based on the state of the art of site evaluation these soils suggest no obstacle to system siting and loading at a high rate (i.e. 5 cm/d). Further, based on the current state of practice these soils would likely be assumed to provide excellent wastewater renovation.

Applied Wastewater Characteristics

Wastewater Flow --

The average daily wastewater flow at Westboro was determined by recording the discharge cycles of the siphons deliverying wastewater to the soil absorption system. Based upon measurements made between June 24, 1981 and October 5, 1982, approximately one siphon discharge occurred daily representing an average daily flow of 32.2m^3/d (8,506 gal/d) (Table A6).

During this study, Beds 2 and 3 were used exclusively while Bed 1 was rested. With two absorption beds in service, the average daily flow resulted in a wastewater application rate of approximately 1.4 cm/d (0.33 gpd/ft^2) of bottom area. Under normal operation, the siphon would alternately discharge 2.8 cm/d (0.56 gpd/ft^2) to each operating bed, but only every other day.

The daily flow volume measured in this study was roughly 16 percent higher than the 27.8 m^3/d (7,345 gal/d) flow determined during 1978 based upon monitoring of the pumps in the main lift station feeding the siphon chamber (Otis, 1978). This increase is probably due in large part to the increased number of connections now contributing to the daily flow. The actual daily flow of 32.2 m^3/d measured during this study was equal to only 28 percent of the design capacity of the soil absorption system.

Wastewater Composition --

The composition of the septic tank effluent (STE) delivered to the soil absorption system was determined from grab samples collected from the siphon chamber between September 18, 1981 and May 5, 1983. The STE contained substantial concentrations of organic matter (168 mg/L BOD$_5$), suspended solids (85 mg/L), total nitrogen (63 mgN/L) and fecal coliform bacteria (10^7 organisms/L) (Table A7). The composition of the STE at Westboro was generally within the range of values determined in previous studies of individual homes and multiple-home developments (Tables 4 and A8). Comparison of the STE mass loadings calculated at Westboro with typical values for raw household wastewaters enabled a crude estimate of the maximum pollutant removals achieved with septic tank pretreatment: BOD$_5$ - 54%, TSS - 77%, N - 49%, and P - 78% (Table A9).

Soil Infiltrability

The infiltrability of the wastewater absorption beds was indirectly measured through monitoring of the occurrence and magnitude of wastewater ponding within each bed. Records indicated that ponding was noted in all three beds as early as June 1979, less than two years after startup. This is in itself not surprising as subsurface wastewater absorption systems commonly operate in a continuously ponded state after as little as nine months of service (Bouma, 1975).

Table A6. Daily Wastewater Flow Volume.

Period		Days	Siphon Cycles	Cycles/day*	Flow** (m^3/d)
From	To				
6/24/81	7/28/81	34.4	58	1.70	54.1
7/28/81	8/25/81	27.7	18	0.65	20.7
8/25/81	8/27/81	2.05	2	0.98	31.2
10/01/81	10/20/81	19.2	20	1.04	33.1
10/22/81	11/18/81	26.6	19	0.71	22.6
11/18/81	12/01/81	13.1	10	0.76	24.2
12/01/81	4/27/82	147.6	168	1.14	36.3
4/28/82	6/08/82	40.8	41	1.00	31.8
6/08/82	6/10/82	2.2	2	0.91	29.0
6/10/82	7/13/82	32.8	24	0.73	23.2
7/13/82	7/15/82	2.2	2	0.91	29.0
7/15/82	8/03/82	19.1	13	0.68	21.7
8/24/82	10/5/82	41.8	37	0.89	28.3
TOTAL		409.6	414	-	-
AVERAGE (Weighted)		-	-	1.01	32.2

* 1 cycle = 31.85 m^3 (8415 g). ** gpd = 264.2 x m^3/d.

Table A7. Septic Tank Effluent Composition.

Parameter	Units	Samples	Mean	S.D.	Minimum	Maximum
BOD_5	mg/L	4	168	37	120	204
COD	mg/L	6	338	42	291	414
TDS	mg/L	4	576	84	478	658
TSS	mg/L	4	85	46	31	142
TKN	mgN/L	6	57	10	42	70
NH_4N	mgN/L	6	44	19	11	60
NO_3-N	mgN/L	6	6.4	4.5	0.9	13.0
TP	mgP/L	6	8.1	1.9	6.4	10.8
p^H	-	3	-	-	6.9	7.4
Cl^-	mg/L	6	62	28	19	104
COND.	μmhos/cm	6	1073	104	968	1245
F. Coli	Log#/L	4	7.3	0.35	6.92	7.64
F. Streptococci	Log#/L	4	5.7	0.30	5.32	6.00

Table A8. Per Capita Mass Loadings, gmcd (lb/cap/d).

	Location				
Parameter	Westboro, WI.	Bend, OR.	Glide OR.	Manila, CA.	Range
BOD_5	22.8 (0.050)	23.7-35.6 (0.052-0.078)	21.4 (0.047)	28.5-40.8 (0.063-0.090)	21.4-40.8 (0.047-0.090)
TSS	11.6 (0.025)	5.4-8.2 (0.012-0.018)	9.5 (0.021)	11.3-16.2 (0.025-0.036)	5.4-16.2 (0.012-0.036)
TKN	7.8 (0.017)	6.2-9.3 (0.014-0.020)	9.1 (0.020)	- -	6.2-9.3 (0.014-0.020)

* Based upon the data presented in Table A7 and Table 4.

Table A9. Estimated Pollutant Removals Afforded by Septic Tank Pretreatment at Westboro.

Parameter	Raw Wastewater*	Septic Tank Effluent**	Estimated % Removal
BOD_5	35-50 gmcd	22.8 gmcd	35-54%
TSS	35-50 gmcd	11.6 gmcd	67-77%
N	6-17 gmcd	8.6 gmcd	0-49%
P	3-5 gmcd	1.1 gmcd	63-78%

* Based upon data presented in U.S. EPA, 1980, Table 4-3.
** Mean results from Table A8.

The first measurements of this study were made on June 23, 1981. These revealed significant levels of ponding. Beds 2 and 3 were in service at the time and both were found to have approximately 18 in. (46 cm) of STE ponded above their bottom infiltrative surfaces. The design of the beds called for 12 in. (30 cm) of gravel above the soil infiltrative surface followed by a 4-in. (10 cm) distribution lateral and 2 in. (5 cm) of gravel on top of that. This yielded a total bed depth of about 18 in. (46 cm). During the course of the study, the level of ponding fluctuated somewhat, but both operating beds remained basically fully ponded.

The average daily wastewater application rate was measured at 1.4 cm/d based upon bottom area alone. Assuming all of the wastewater applied to the beds under normal operation infiltrated into the bottom of the beds, the 1.4 cm/d can be viewed as roughly equal to the infiltration capacity of the ponded absorption system. Even at 1.4 cm/d the infiltration capacity of the beds was less than 50 percent of an apparently conservative design loading rate of 3.0 cm/d for this site based upon the slowest percolation rate measured in this study (see Soil and Site Characteristics section). The results of efforts to determine possible cause(s) for the lower than expected infiltration capacity are described below.

During installation of the subsurface monitoring instruments, in Bed 2, the infiltrative surface was visually inspected and sampled. At both locations within the bed (Figure 3, Point A,C), the gravel was found to be intimately meshed with the natural sand surface. The gravel was relatively large (2 in.) and contained some platy fragments. The infiltrative surface in Bed 2 did not exhibit a surface clogging mat as such, but rather a clogging zone. The sandy soil was black in color to a depth of approximately 2 to 3 in (5 - 8 cm) and was quite wet. By 6 to 8 in., (15-20 cm), however, the sand had graded to natural coloration and felt only moist. These observations were consistent with previous work, regarding the visual characteristics of subsystem clogging zones (Bouma, 1975; Anderson, et al., 1982).

Soil samples were collected with depth during installation of the groundwater observation well at Location A (Figure 3) on November 18, 1981. Very high volumetric moisture contents (33.9 and 37.8%) were measured in the upper 4 in. (10 cm) of soil immediately beneath the bottom of the bed. With the total soil porosity estimated at 40 percent, these data suggest that nearly all of the soil pores were water-filled. Below this, at 6 to 8 in (15-20 cm), a much lower moisture content was measured (24.8%). The accumulation of volatile matter (TVS) and nitrogen (TKN) was most pronounced in the soil near the infiltrative surface and decreased with depth. Similar findings have been reported previously (Kristiansen, 1981). These results appear to confirm the visual observations regarding the existence of a zone rather than a surface mat as responsible for reducing infiltration into the subsoil.

Infiltration of septic tank effluent into soil materials has been shown to result in soil clogging which leads to large reductions in infiltrative capacity compared to the natural soil (Avnimelech and Nevo, 1964; McGauhey and Krone, 1967; Laak, 1970; DeVries, 1972; Rice, 1974; Hargett et al, 1982). The reduction of infiltration capacity has been attributed to both physical and chemical causes. In sands, the primary cause appears to be accumulation of wastewater suspended solids and biological organisms and their waste products. Long-term infiltration rates are used to design systems and are supposed to account for these reductions and represent the infiltrative capacity of a mature, clogged soil system.

The work of Bouma (1975) led to the widespread acceptance of design infiltration rates for subsurface wastewater absorption systems based upon major soil types, usually four: Type I - sands, Type II - sandy loams, loams, Type III - silt loams, some silty clay loams, and Type IV - clays, some silty clay loams (U.S. EPA, 1980, Anderson, et al., 1982). Typically the soil type is determined based upon a percolation test or simple morphological inspection and a design infiltration rate chosen accordingly. Careful review of the published results of Bouma (1975) raised questions, particularly regarding the design infiltration rate adopted for systems installed in sandy soils which contain substantial percentages of finer sands, silt or clay matter. The results of Bouma (1975) for the coarse sands studied support his recommended design infiltration rate of 5 cm/d. However, Bouma's results regarding sandy loams were variable and do not support the 3 cm/d recommended design infiltration rate. This recommendation was based upon the measured Soil Moisture Tensions (SMT's) under three ponded but operating individual home systems located in gravelly sandy loams (percolation rates of 6, 6 and 30 min/inch). SMT's of 80, 120 and 65 cm of water, respectively, were measured and combined with hydraulic conductivity curves for each site to yield calculated infiltration rates of only 0.4, 0.03 and 1.9 cm/d, respectively. The relatively higher value for the third system (1.9 cm/d) may have been due, in part, to the fact that it has been in operation only two years compared to six years for the other two systems (Bouma, 1975).

The work of Simons and Magdoff (1979) supports lower design infiltration rates for sandy soils of other than coarse texture. These investigators recommended a maximum safe infiltration rate of 2 cm septic tank effluent per day for sands based upon column studies with a sand containing 33 percent medium and 54 percent fine particles. Otis and Hargett (1983) have also advocated conservative loading rates. The results of this study at Westboro suggest that even 2 cm/d may be too high for large bed systems installed in fine sands.

Subsystem Soil Moisture and Gas Characteristics

Soil Moisture Conditions --

Soil moisture tensions (SMT) were measured at two depths at each of three locations under and beside Bed 2 (Table 5). All SMT values in this discussion are expressed as cm of water. The SMT's measured under Bed 2 were similar at both depths below the infiltrative surface suggesting that flow in the soil was under unit gradient, due only to gravitational forces. Under the Bed, the SMT's ranged from 21 to 44 cm. The resistance to infiltration, R_b, was calculated according to the method of Bouma (1975) to equal approximately 60 days (using an SMT = 34 cm, a ponding head = 46 cm, a clogging zone thickness = 4 cm, and an infiltration rate of 1.4 cm/d).

The SMT's measured outside of the Bed (Point B) fluctuated from 0 to 61 cm (Table 5). Since no liquid ponding was present over this location and steady infiltration was not occurring, soil moisture conditions and the resulting SMT's were no doubt affected by antecedent precipitation and other climatic influences.

The SMT's measured under Bed 2 at Westboro were within the range of values measured previously by Bouma (1975). Bouma found that the SMT's under four ponded but operating individual home systems located in coarse sands ranged from 23 to 25 cm water while those measured under three ponded systems located in gravelly sandy loams ranged from 65 to 120 cm water. The latter SMT values indicated dryer subsurface soil conditions under wastewater absorption systems installed in finer textured soils. Bouma (1975) suggested that the dryer subsystem soil moisture conditions were induced by a more restrictive clogging zone (Bouma, 1975).

Curves relating soil moisture tension data and hydraulic conductivity can be derived for a given soil system utilizing the crust-test procedure (Bouma, et al., 1972; Bouma, et al., 1974). Typical hydraulic conductivity curves for four major soil types have been proposed by Bouma (1975) as shown in Figure A6. Also shown are the approximate hydraulic conductivity and soil moisture tension data measured in this study. With a knowledge of the soil materials at the site, the measurements made at Westboro appear similar to those predicted by the generalized curve of hydraulic conductivity for a sandy soil material (Figure A6). This is a Type I soil according to Bouma's classification. Interestingly, the design loading rate often recommended for wastewater absorption systems installed in Type I soils is 5 cm/d (Bouma, 1975). The operating infiltration capacity of the Westboro system, estimated at only 1.4 cm/d, suggests that hydraulic conductivity curves may not be sensitive enough to predict long-term wastewater acceptance rates.

Soil Pore Gas --

Samples of soil pore gas were collected at the same locations at which the SMTs were measured (Table 6). Concentrations of CH_4 gas were 19.1 and 17.9 percent at 30 and 75 cm depths beneath the infiltrative surface of the bed, respectively. Concentrations of CO_2 gas were 3.8 and 4.1 percent at these same depths. Both of these gases are produced as a result of microbial respiration under anaerobic conditions. Concentrations of CH_4 and CO_2 measured at the edge of the bed were similar to those measured beneath the bed, suggesting that little horizontal diffusion of O_2 was occurring from the natural soil surrounding the bed or that it was insufficient compared to the O_2 demand exerted. The low concentrations of O_2 measured were believed to be due to atmospheric contamination of field samples during sampling or transport. Previous researchers have reported similar contamination problems (Lance, et al., 1973). These gas data indicated that the wastewater percolating through the unsaturated soil beneath the system was very likely undergoing anaerobic treatment.

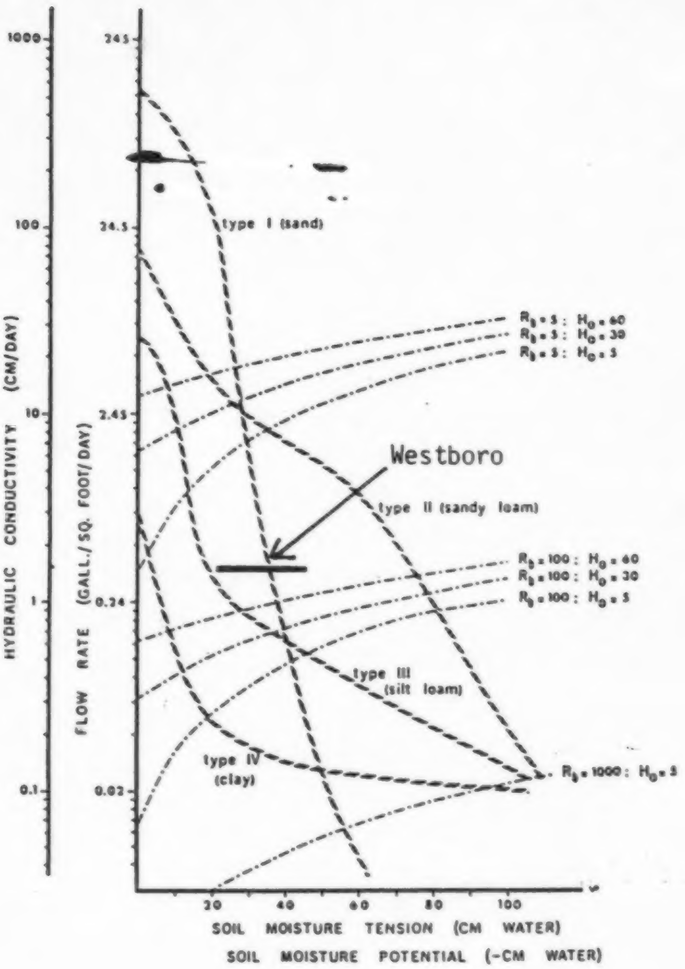


Figure A6. Typical Hydraulic Conductivity Curves (Bouma, 1975) and the Measurements Made at Westboro, Wisconsin.

The soil gas composition measured in this study was unexpected based upon the known results of earlier investigators (e.g., Walker et al., 1973; Sikora and Corey, 1976). However, previous work had addressed only small single-home systems. If anaerobic conditions characterize the soil system beneath large bed subsurface wastewater absorption systems, questions arise concerning the wastewater infiltration and purification characteristics of these systems. Much of the data characterizing the performance capabilities of subsurface wastewater absorption systems has been obtained from laboratory experiments involving soil columns or small lysimeters (e.g., Robeck, et al., 1963, 1964; Schwartz and Bendixen, 1970; DeVries, 1972; Lance, 1977; and Tare and Bokil, 1982). The physical and environmental characteristics of the soil systems in th labs experiments may produce soil aeration dramatically different from that experienced in the field under operating systems. This may be particularly true for large rectangular or square bed systems.

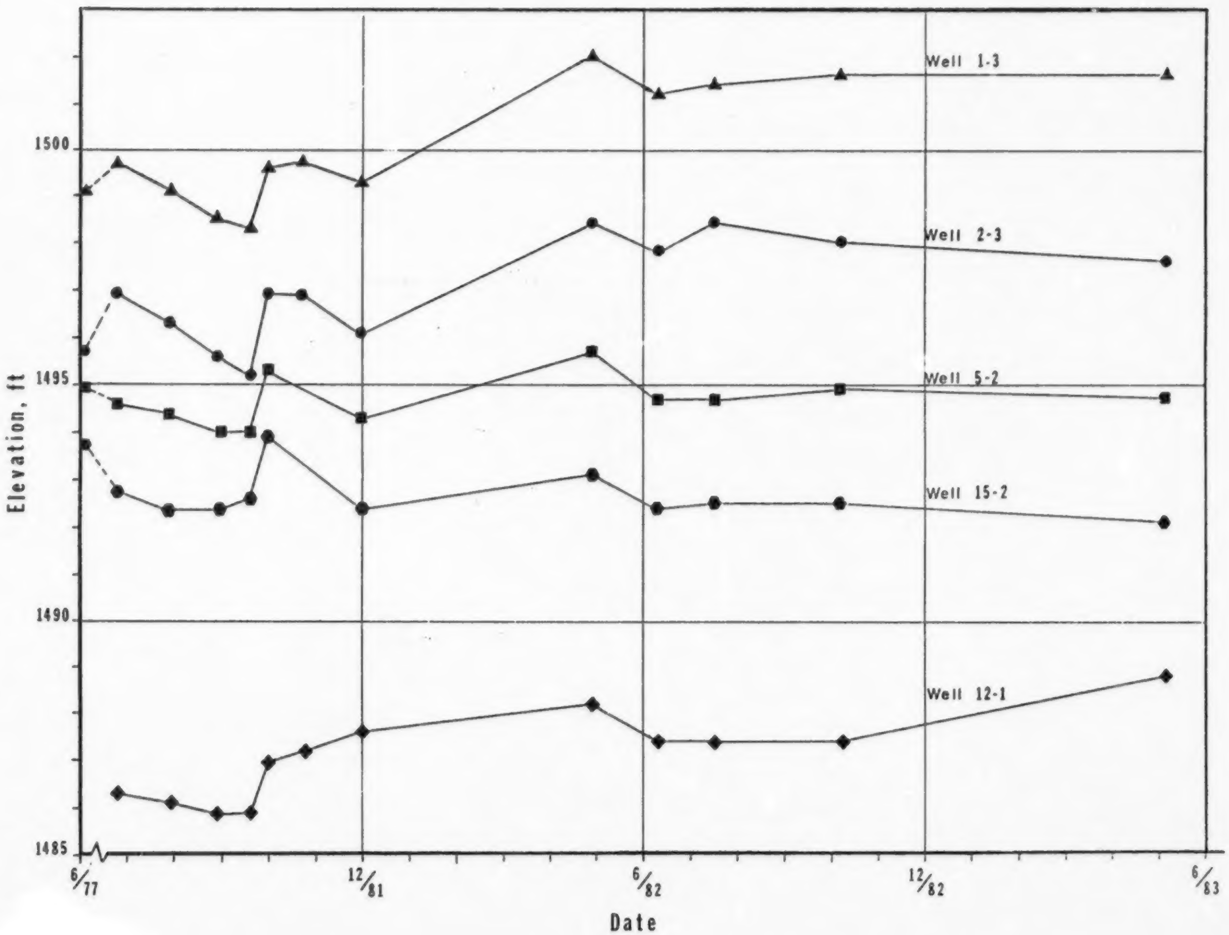
Siegrist et al. (1984) suggested that subsystem anaerobiosis may characterize large bed systems since the wastewater-induced oxygen demands can exceed the oxygen transfer capacity of the system. Anaerobiosis may not occur initially but may develop after some period of operation when oxygen diffusion through the infiltrative surface has been reduced to a critical level due to the effects of soil clogging. Based upon a preliminary review of the literature, Siegrist et al. (1984) reported that subsystem aeration may significantly affect the performance of a subsurface wastewater absorption system, but the nature and magnitude of the effects are known only qualitatively. The loss of infiltration capacity as a result of soil clogging was reported to be more rapid under anaerobic conditions, although it was unclear if long-term infiltration capacity or system longevity are diminished. Percolation through an anaerobic as compared to an aerobic vadose zone was found to diminish the degradation of certain pollutants such as organic matter and ammonia nitrogen, increase that of other pollutants such as phosphorus and certain complex organics, while having variable effects on the others such as coliform bacteria.

Groundwater Characteristics

Groundwater Potentials and Flow --

Groundwater potentials were measured over a 22-month period between August 27, 1981 and October 6, 1982. During this period, absorption beds 2 and 3 were in operation. The shallow observation wells (2.4 m maximum penetration) at sixteen locations across the site were used to determine groundwater surface elevations (Figure 3, Table A4). The groundwater surface measured at representative wells over the course of this study are shown in Figures A7 to A9. As shown, the groundwater surface elevation fluctuated over the monitoring period. All wells showed approximately the same pattern, indicating that the variations were seasonal or due to precipitation. Previous monitoring at Westboro showed similar variations (Otis, 1978).

Only wells 1-15 were installed at Westboro before startup of the system in September 1977. The groundwater surface elevation at these wells in June,



Fi[illegible]e A7. Groundwater Surface Elevations Measured at Wells 1, 2, 5, 12 and 15.

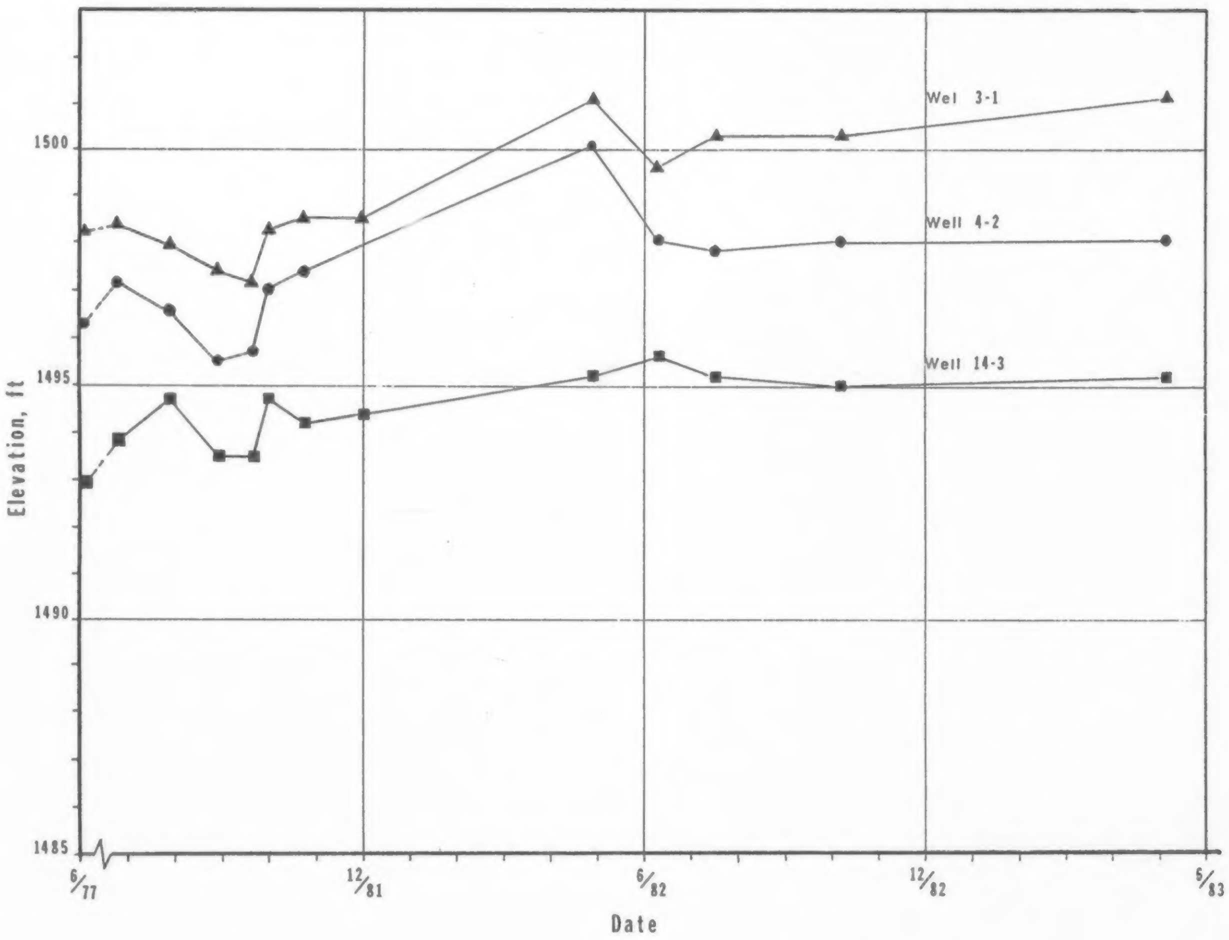


Figure A8. Groundwater Surface Elevations Measured at Wells 3, 4 and 14 Versus Time.

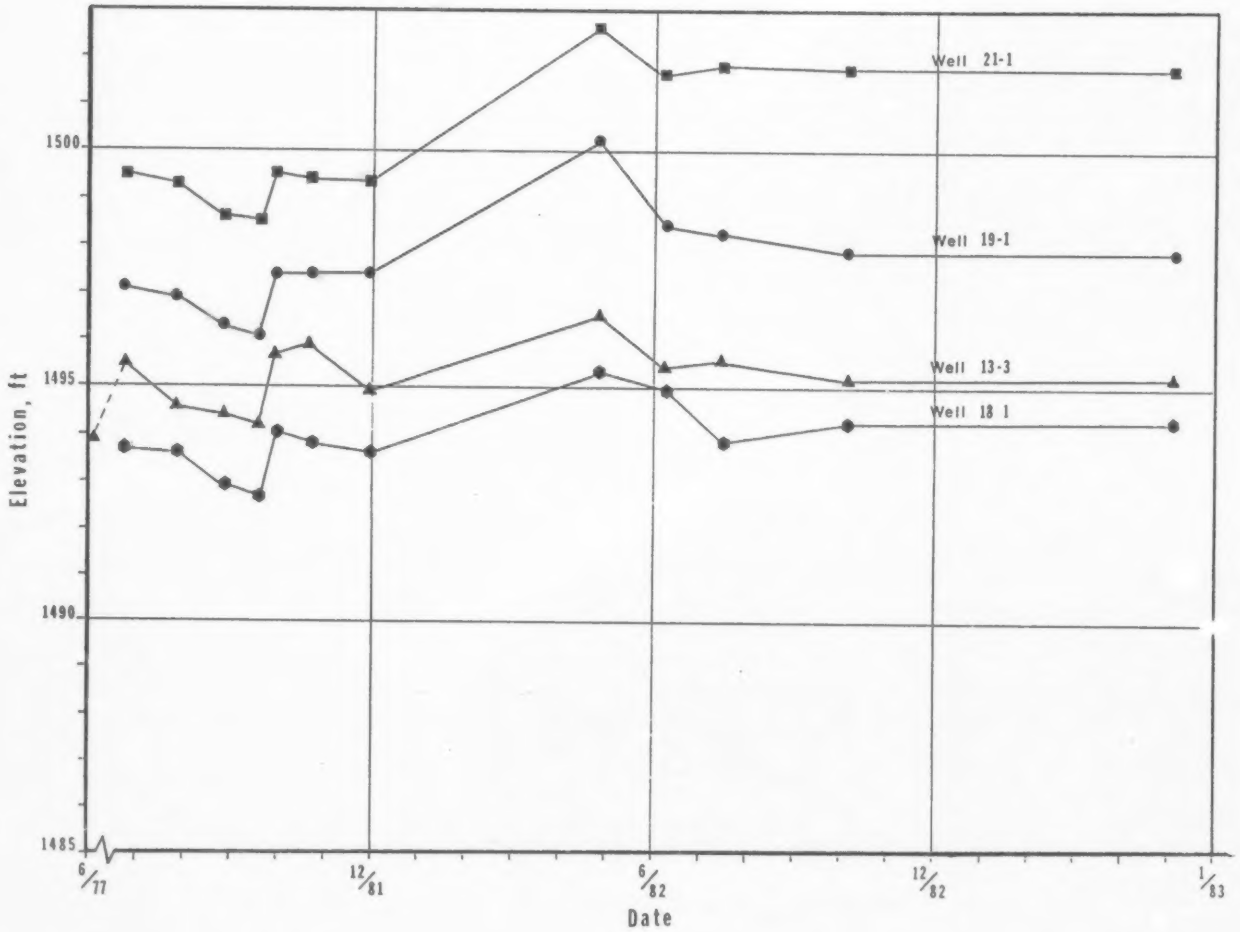


Figure A9. Groundwater Surface Elevations Measured at Wells 13, 18, 19 and 21 Versus Time.

1977 is shown on the elevation axis in Figures A7 to A9. These pre-startup elevations lie within the ranges of elevations measured during this study for all the shallow wells except wells 13-3 and 14-3. The pre-startup levels of these two wells are lower than the lowest value measured since startup. These are also the only two original wells in the immediate vicinity of the beds. This suggests that the water table has been affected by the continuous application of wastewater. Unfortunately, wells 17-22 and A-D were not installed until well after system startup, and cannot be used to confirm this observation.

To delineate the groundwater surface and to estimate groundwater flow patterns the multi-dimensional spline smoothing routine was coupled with a computer contour plotting routine and graphics system to obtain computer drawn groundwater contour maps. This computer-mapping technique was compared to manual mapping methods and judged to be acceptable for the purposes of this study (Anderson et al., 1984).

Contour maps of the groundwater surface in the vicinity of the absorption beds for three dates during the period of this study are shown in Figures 4, A10 and A11. Although elevations fluctuated with time as discussed earlier, contour patterns stayed very much the same. These patterns indicated multidirectional groundwater flow under the absorption beds. The general flow pattern was as expected based upon surface topography which slopes from northwest to southeast and downward to Silver Creek. However, other minor patterns were also noted. The groundwater surface was elevated in an area extending from west to Bed 3 to under Bed 3 with groundwater flow radiating out to the northeast, east and southeast (Figures 4, A10 and A11). This pattern suggested that a small recharge area existed west of Bed 3. A low-lying marshy area was located approximately 61 m (200 ft) west of Bed 3 (Figure 3) and could have been partly responsible for the pattern indicated. The groundwater maps also showed flow patterns associated with the drainage ditch located south of the absorption beds (Figure 3).

In general, groundwater flow patterns measured in this study did not differ substantially from those reported to exist before and shortly after system startup (Otis, 1978). However, insufficient monitoring facilities at that time did not allow delineation of groundwater levels close to the absorption beds.

Using the groundwater contour maps, Darcy's Law, and the Dupuit-Forchheimer assumption, the direction and velocity of groundwater flow at various locations was estimated. Darcy's Law states that:

$$V=K\frac{dH}{dL} \qquad (1)$$

where, V=velocity, cm/d

K=soil permeability, cm/d

$\frac{dH}{dL}$=hydraulic gradient, cm/cm

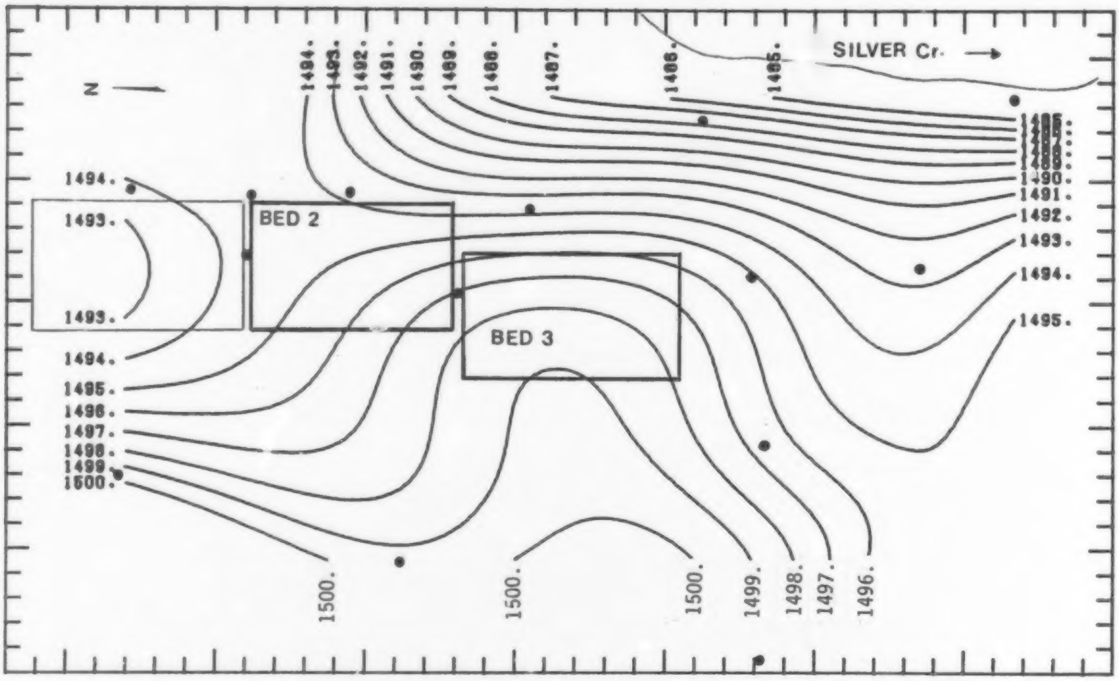

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Figure A10. Computer-Generated Contour Map of the Groundwater Surface on October 22, 1981 (See Figure 3 for Site Plan; Scale: 1 unit = 3.75 ft).

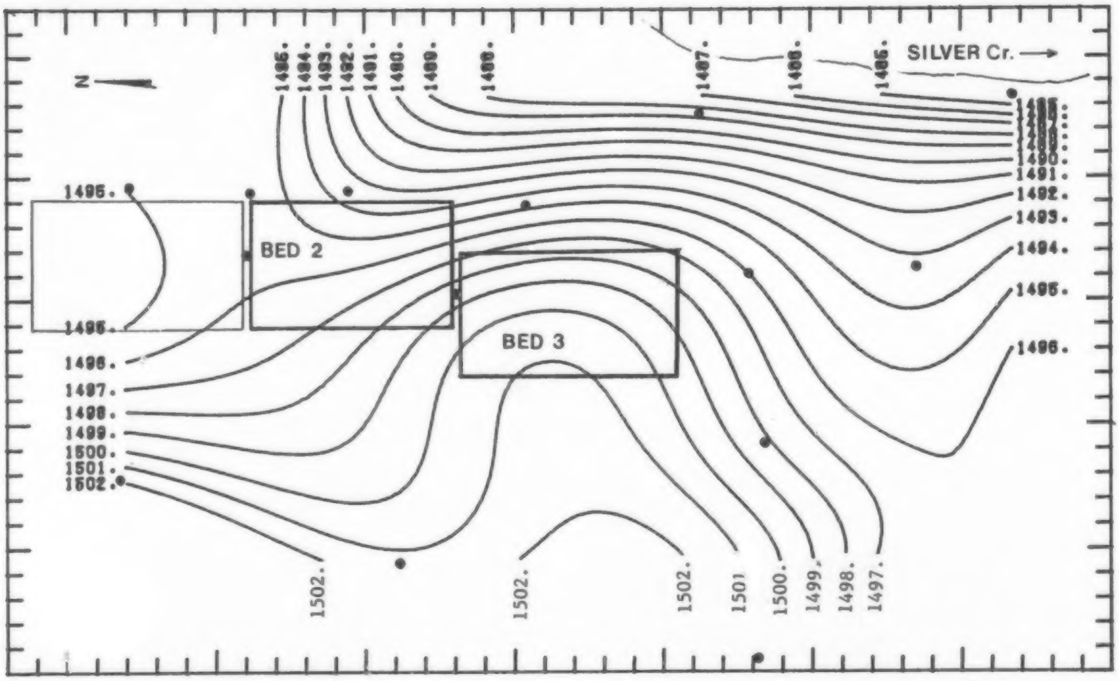
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Figure A11. Computer-Generated Contour Map of the Groundwater Surface on April 28, 1982 (See Figure 3 for Site Plan; Scale: 1 unit = 3.75 ft).

Soil permeability values determined at Westboro varied widely, but a K_{sat} of 500 cm/day was assumed to be representative of most of the sandy materials at the site, based on soil stratigraphy and permeability data (see soil and site characteristics). Table A10 compares the velocity values estimated for A12 various permeabilities at three locations near the site while Figure 17 shows the location and direction. These estimates were derived from the groundwater contour maps for August 17, 1981 (Figure 4 and A12). Although elevations fluctuated, the hydraulic gradient did not change significantly on other dates.

The highest velocity occurred directly to the east of Bed 3, the area of the most permeable soils and greatest hydraulic gradient. Assuming a K_{sat} of 500 cm/day (16.4 ft/day) a velocity of approximately 40 cm/d (1.3 ft/day) was calculated in this area. This value was within the normal range for groundwater flow given by Todd (1966). At this rate it would take approximately 115 days for groundwater from under the beds to reach Silver Creek.

The vertical and horizontal hydraulic gradients estimated at three of the nested well sites are given in Table A11. These estimates were based on the differences in groundwater potentials measured at the nested wells and on the contour plots. The vertical hydraulic gradient was approximately 7 to 10 times the horizontal gradient based on these estimates. Despite these relatively high vertical gradients relative to the horizontal gradient, the vertical groundwater flow may be insignificant compared to horizontal flow due to the fluvial character of the aquifer sediments (Karnauskas and Eisen, 1977).

Mounding of groundwater under wastewater absorption systems has become of greater concern as the size of such systems has increased to include subdivisions and small communities. The critical concern regarding groundwater mounding is that the water table may rise and reduce the depth of unsaturated soil to the point where adequate treatment may not occur prior to groundwater recharge.

Several models have been developed to estimate the groundwater mounding which may occur due to wastewater application (Allen, 1980; Parker, 1982; Fielding, 1982; EPA, 1981; Finnemore and Hantzsche, 1983). Most commonly these models use the Hantush procedure for calculating groundwater rise (Hantush, 1967). A simplified procedure based on the Hantush method and applied specifically to on-site wastewater treatment systems has been developed by Finnemore and Hantsche (1983). This method was used to estimate the magnitude of groundwater mounding at Westboro as follows.

For groundwater recharge over long time periods (i.e., years) the maximum water table rise, Zm, can be estimated by:

$$Zm = IC \left[\frac{L}{4}\right]^{n} \left[\frac{1}{Kh}\right]^{0.5n} \left[\frac{t}{Sy}\right]^{1-0.5n} \qquad (2)$$

where,

I=wastewater loading rate, ft/day

Table A10. Estimated Horizontal Groundwater Velocities.

Location **	Direction	K		Estimated Velocity	
		cm/day	ft/day	cm/day	ft/day
A	ESE	100	3.3	8	0.3
		500	16.4	41	1.4
		1000	32.8	82	2.7
B	SE	100	3.3	4	0.1
		500	16.4	19	0.6
		1000	32.8	38	1.2
C	NE	100	3.3	2	0.1
		500	16.4	12	0.4
		1000	32.8	24	0.8

* Based upon August 27, 1981 groundwater surface contours.
** Refer to Figure A12 for locations.

Table A11. Estimated Horizontal and Vertical Hydraulic Gradients at Nested Wells*.

Well **	m/m Vertical	m/m Horizontal
13-1,2,3	0.36	0.05
1-1,2,3	0.17	0.02
2,1,2,3	0.36	0.03

* Based on potentials measured June 23, 1981.
** Refer to Figure 3 for locations.

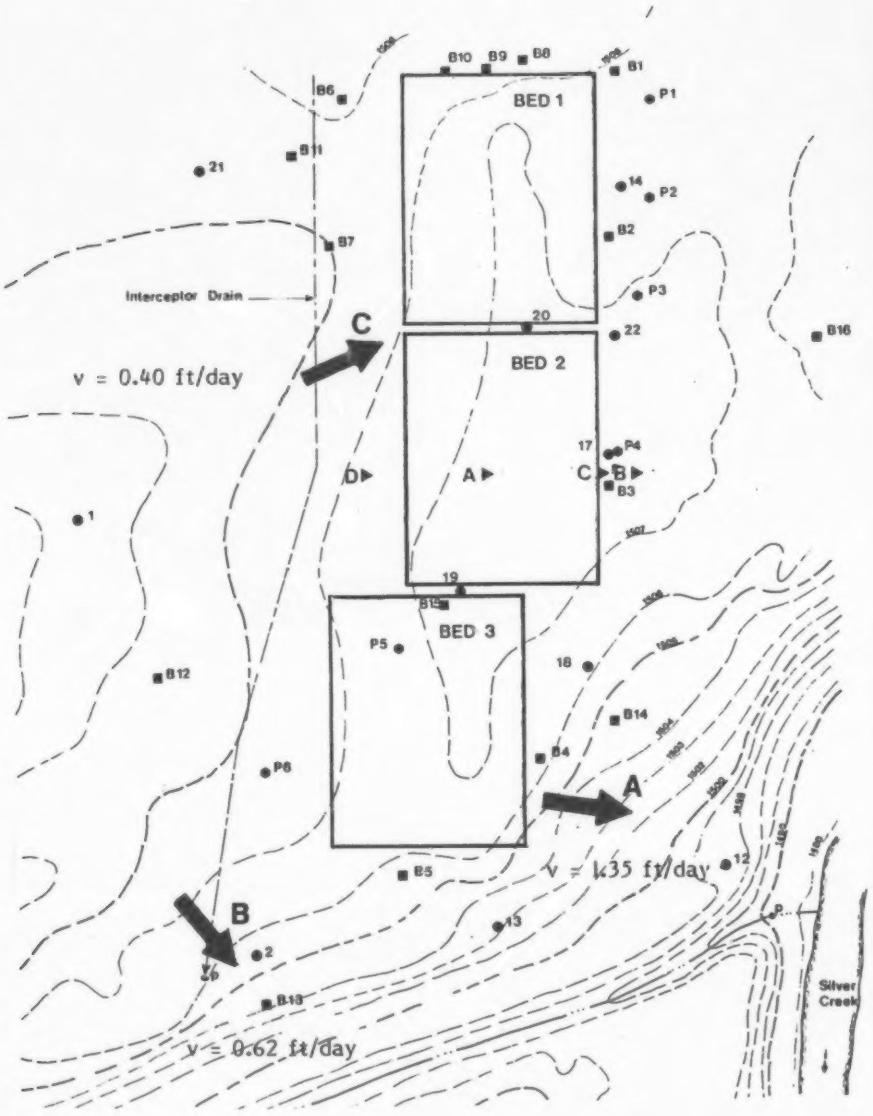
B10
B9
B8
B1
B6
BED 1
P1
B11
21
14
P2
B2
B7
P3
Interceptor Drain
20
22
C
B16
BED 2
v = 0.40 ft/day
17
P4
D
A
C
B
B3
1
1507
19
B15
BED 3
1506
1505
P5
18
B12
B14
1504
1503
B4
1502
1500
1498
P6
A
1496
1490
v = 1.35 ft/day
12
B5
P
B
13
2
B13
Silver Creek
v = 0.62 ft/day

Figure A12. Approximate Velocities Using Darcy's Law and a Soil Permeability of 500 cm/day (Based on contour maps for August 27, 1981 - Figure 4).

C,n=constants dependent on disposal field geometry, from Table 1 in Finnemore and Hantzsche (1983)
L=length of disposal field, ft
K=saturated horizontal conductivity of aquifer, ft/d
$h=h_o+\frac{Zm}{2}$
h_o=depth of saturated zone. Can assume $h=h_o$ for approximation
t=time since beginning of wastewater application.
Sy=specific yield of aquifer (0-1.0)

Application of this model at Westboro was based upon the following site data.

I=0.0437 ft/day (1.4 cm/d)
L=260 ft (79.2 m) (both beds)
K=16.4 ft/d (500 cm/day)
h_o=90 ft (27.4 m)
t=2190 days
Sy=0.20
C=1.7928
n=1.76012

Using Eg. 2, the groundwater mounding under the absorption beds was calculated to be approximately 18 cm (0.60 ft). This is consistent with the data presented by Finnemore and Hantzche (1983) according to which groundwater mounding would not be anticipated due to the high permeability (5 m/d) and thickness (27.4 m) of the underlying aquifer. In general, where aquifer thickness exceeds 12.2 m (40 ft) and permeabilities exceed 1.5 m/d (5 ft/d), groundwater mounding should be less than 30 cm (1 ft), regardless of system size or geometry.

Inspection of the groundwater contour plots (Figures 4, A10 and A11) suggested that some groundwater mounding may have been present under the absorption beds. In an attempt to quantify the occurrence and magnitude of any mounding, groundwater elevations were measured along a west to east transect under Bed 2. A profile of the groundwater surface along this transect is shown in Figure A13. This profile runs from observation well 1-3 to well B. Under Bed 2, the groundwater surface was measured at 90 to 130 cm (3 to 4.3 ft) below the bottom of the bed. Normally one might expect a relatively uniform curve of the groundwater surface following that of the site topography. In contrast, the profile revealed a rapid drop-off in the groundwater surface just east of the absorption bed (Figure A13). Assuming a uniform elevation change with distance under the bed if wastewater application was not occurring, an estimate of the apparent groundwater mounding can be made by connecting the elevations measured at Well D and B and comparing the interpolated value with that measured at Wells A and C. Data for July 5, 1983 indicated mounding of 18 cm (0.6 ft) near the center of Bed 2 (Well A) and 64 cm (2.1 ft) near the east edge (Well C).

The discrepancy between the field results and the model predictions are believed to be due to the non-homogeneous character of the site conditions at Westboro and the potential site variability of the estimated model parameters.

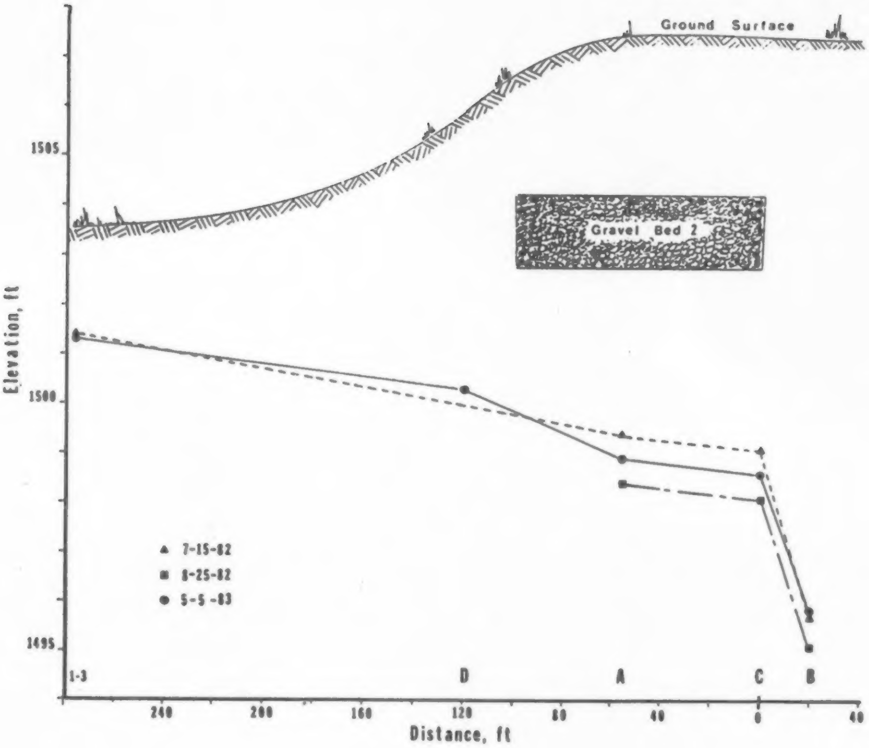

Figure A13. Profile of the Groundwater Surface Under Bed 2 (Note: Exaggerated Vertical Scale).

Finnemore and Hantzche (1983) emphasized that their model was only applicable to flow systems involving a single permeable layer with a horizontal impermeable boundary underlying it. They also stated that available models to predict groundwater mounding were theoretical and in need of field verification.

Groundwater Composition --

The qualitative characteristics of the groundwater in the vicinity of the wastewater absorption beds were determined through sampling of 25 groundwater monitoring wells (Figure 3). The results of this monitoring are tabulated in Tables A12 to A14.

The multi-dimensional spline smoothing routine was also applied to the groundwater quality data to map contour levels for the parameters measured. Figures A14 and A15 show contour maps for total dissolved solids (TDS) and ammonia nitrogen (NH_4) on August 27, 1981. The computer maps all showed peak levels of the plotted parameters at the southeast corner of Bed 3, decreasing radially from there. This agrees with the well data and groundwater flow results discussed earlier.

Based on the flow patterns developed from the groundwater elevation analysis, several wells were chosen to characterize the upgradient groundwater quality. Wells 1-3, 3, and 21 were most suitably located for this purpose (Figure 3). The mean concentrations of the parameters monitored are shown in Table A15. The values are generally consistent between wells and indicate the background water quality in the top 1.8 to 2.4 m (6 to 8 ft) of the groundwater. Differences in concentrations of chloride and conductivity may be due to well spatial location or penetration into the groundwater. All parameters were generally below the recommended values for drinking water (Bouwer, 1978).

The monitoring wells located close to the absorption beds revealed significant increases in the concentrations of measured parameters in the groundwater relative to background levels (Table 7). In particular, samples from the shallow wells 13-3, 18 and 19 located near and downgradient from Beds 2 and 3 exhibited mean concentrations of total dissolved solids, chlorides and conductivity not significantly different ($\alpha = 0.05$) from the concentrations in the applied wastewater (Table A7 and A15). These are conservative parameters which should not be attenuated or removed in the soil treatment system. The fact that the concentrations in the shallow groundwater were equal to that of the applied wastewater indicated that the monitoring wells were installed so that samples were withdrawn within the effluent plume.

The mean ammonia nitrogen concentrations measured at wells 13-3, 18 and 19 were 45.7, 41.5 and 33.1 mg N/L, respectively (Tables 8 and A13). These values were approximately 100 times greater than background levels and not significantly different from the NH_4^+ concentrations of the applied wastewater (Table 8). These data indicated that little nitrification of the applied NH_4^+ was occurring.

Table A12. Qualitative Characteristics of the Groundwater in the Vicinity of the Wastewater Absorption Beds - Dissolved Solids, Chlorides and Conductivity*.

Well**	Sample Elevation+	TDS (mg/L)			CL$^-$ (mg/L)			Conductivity (µmhos/cm)		
		n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.	n	$\bar{x}$	s.d.
1-3	1496.4	7	170	30.7	9	14.3	4.0	6	150	19
-2	1493.0	7	180	39	9	15.6	4.4	6	161	15.7
-1	1470.6	7	295	110	9	2.4	1.0	6	234	11
2-3	1491.6	7	406	101	9	51.0	22	6	437	162
-2	1483.9	7	471	53	9	50.4	9.0	6	686	37
-1	1471.7	7	273	41	9	2.6	0.6	6	288	18.7
3-1	1493.6	7	157	34.4	9	2.1	1.0	6	95	26
5-2	1487.2	6	343	119	8	5.2	1.5	5	476	106
-1	1477.2	6	435	93	8	20.2	8.6	5	576	166
11-1	1474.9	6	216	81.6	8	3.9	0.9	5	207	87.7
12-1	1481.6	7	407	64	9	25	12	6	551	123
13-3	1488.1	7	495	78	8	65	6.2	6	1015	104
-2	1477.9	7	341	90	8	14	5.5	6	470	107
-1	1467.1	7	173	51	9	3.4	2.3	6	219	14.3
14-3	1489.0	7	245	114	9	24	9.9	6	271	30
-2	1477.0	6	244	99	9	13	1.1	6	303	20
-1	1463.4	7	235	114	8	5.3	4.2	6	221	12.7
15-2	1487.5	6	380	134	8	20	16.4	5	602	149
-1	1477.2	5	218	90	8	4.3	2.6	4	286	15
17	1493.4	2	305	-	4	41.4	4.4	2	555	-
18	1490.4	7	467	90	9	63.1	10.6	6	1025	115
19	1493.4	7	480	27	9	66	5.6	6	960	76
20	1490.0	7	404	46.8	9	56.1	17.6	6	538	114
21	1492.4	6	155	36	6	10.7	3.6	2	106	0.2
22	1491.3	6	251	89	7	25.5	13.2	4	363	56.4

* Based upon grab samples collected between August 27, 1981 and October 6, 1982.

** Refer to Figure 3 for well locations.

+ Taken as the elevation of the middle of the well screen.

Table A13. Qualitative Characteristics of the Groundwater in the Vicinity of the Wastewater Absorption Beds - Nitrogen*.

Well**	Sample Elevation+ (ft)	TKN (mg-N/L)			NH4+ (mg-N/L)			NO3⁻ (mg-N/L)		
		n	$\overline{x}$	s.d.	n	$\overline{x}$	s.d.	n	$\overline{x}$	s.d.
1-3	1496.4	6	0.62	0.19	8	0.21	0.17	5	2.74	0.48
-2	1493.0	6	0.62	0.19	9	0.15	0.07	9	2.30	0.98
-1	1470.6	6	0.66	0.21	9	0.24	0.24	9	1.67	0.88
2-3	1491.6	6	2.00	0.38	9	0.58	0.25	9	16.09	9.92
-2	1483.9	6	1.05	0.86	9	0.17	0.08	9	1.70	0.74
-1	1471.7	6	3.21	0.88	9	1.58	1.13	9	1.27	0.65
3-1	1493.6	6	0.78	0.30	9	0.30	0.11	9	2.01	1.23
5-2	1487.2	5	2.75	0.80	8	2.10	0.58	8	1.55	0.74
-1	1477.2	5	3.50	0.50	8	3.29	0.72	8	1.31	0.73
11-1	1474-9*	5	0.68	0.25	8	0.15	0.08	8	1.61	1.01
12-1	1481.6	6	1.23	0.34	9	0.72	0.21	9	1.70	1.10
13-3	1488.1	6	50.08	5.53	9	45.7	6.51	9	2.52	1.55
-2	1477-9*	6	2.02	0.29	9	1.27	-.71*	9	1.10	0.74
-1	1467-1*	6	1.13	0.26	9	0.88	0.54	9	0.92	0.62
14-3	1489.0	6	2.15	1.17	9	1.28	0.85	9	4.48	2.81
-2	1477.0	6	0.72	0.35	9	0.31	0.29	9	1.52	0.73
-1	1463.4	5	0.94	0.43	8	0.91	1.28	8	1.36	0.92
15-2	1487.5	5	0.78	0.32	8	0.25	0.21	8	1.40	0.75
-1	1477.2	5	0.66	0.18	8	0.40	0.44	8	1.54	0.86
17	1493.4	2	0.78	-	5	1.02	1.05	5	7.54	-
18	1490.4	6	49.3	5.44	9	41.5	4.1	9	4.28	4.60
19	1493.4	6	40.6	8.0	9	33.1	7.6	9	1.64	0.61
20	1490.0	6	2.72	1.69	9	3.01	2.08	9	1.22	0.87
21	1492.4	5	0.62	0.13	8	0.30	0.37	7	2.5	0.65
22	1491.3	5	0.52	0.20	8	0.20	0.15	8	4.13	3.42

* Based upon grab samples collected between August 27, 1981 and October 6, 1982.

** Refer to Figure 3 for well locations.

+ Taken as the elevation of the middle of the well screen.

Table A14. Qualitative Characteristics of the Groundwater in the Vicinity of the Wastewater Absorption Beds - Phosphorus, Chemical Oxygen Demand and Fecal Coliforms*.

Well**	Sample Elevation	TP (mg-P/L)			COD (mg/L)			Fecal Coli. (#/100 mL)		
		n	$\bar{x}$	s.d.	n	min.	max.	n	min.	max.
1-3	1496.4	5	0.08	0.05	2	<5	5	6	0	100
-2	1493.0	5	0.09	0.06	2	<5	<5	6	0	10
-1	1470.6	5	0.21	0.21	1	16	-	5	0	36
2-3	1491.6	5	0.07	0.04	2	12	35	7	0	8
-2	1483.9	5	0.05	0.03	2	17	19	7	0	2
-1	1471.7	5	0.42	0.33	1	57	-	5	0	2
3-1	1493.6	5	0.07	0.04	2	11	35	7	0	10
5-2	1487.2	5	0.11	0.10	2	26	35	5	0	<1
-1	1477.2	5	0.58	0.43	2	16	19	5	0	4
11-1	1474.9	5	0.07	0.05	1	<5	-	4	0	58
12-1	1481.6	5	0.13	0.11	2	19	38	6	0	<1
13-3	1488.1	5	0.11	0.07	2	55	84	6	0	8
-2	1477.9	5	0.30	0.08	2	<5	49	6	0	<1
-1	1467.1	5	0.15	0.01	2	<5	14	6	0	9
14-3	1489.0	5	0.24	0.10	2	12	38	7	0	3
-2	1477.0	5	0.34	0.25	2	<5	52	6	0	<1
-1	1463.4	4	0.32	0.29	2	<5	35	5	0	<1
15-2	1487.5	5	0.05	0.04	2	22	44	5	0	<1
-1	1477.2	5	0.19	9.06	2	13	24	5	0	3
17	1493.4	2	0.23	-	1	26	-	3	0	0
18	1490.4	5	0.12	0.16	2	37	58	7	0	3
19	1493.4	5	0.10	0.14	2	64	86	6	0	3
20	1490.0	5	0.03	0.01	2	24	29	7	0	28
21	1492.4	5	0.03	0.02	2	<5	17	6	0	640
22	1491.3	4	0.03	0.02	1	20	-	6	0	24

* Based upon grab samples collected between August 27, 1981 and May 5, 1983.

** Refer to Figure 3 for well locations.

+ Taken as the elevation of the middle of the well screen.

Table A15. Qualitative Characteristics of the Shallow Groundwater Upgradient of the Absorption Beds*.

Background Well**	TDS mg/L	CL^- mg/L	Cond. $\frac{\mu mho}{cm}$	TKN mg-N/L	NH_4 mg-N/L	NO_3 mg-N/L	TP mg-P/L	COD mg/L	Fecal Coli. #/100 mL
1-3	170	14.3	150	0.62	0.21	2.7	0.08	5	0-300
3	157	2.1	95	0.78	0.30	2.0	0.07	23	0-10
21	155	10.7	106	0.62	0.30	2.5	0.03	11	0-640

* Based upon data presented in Tables A12-A14.

** Refer to Figure 3 for well locations.

The mean concentrations of phosphorus (P) measured at wells 13-3, 18 and 19 were not significantly different than background levels at well 1-3 (Tables 8 and A14). Mass balance calculations were made to determine if the apparent immobilization of P was reasonable. Assuming an influent P concentration of 8.1 mg/L (Table A7) and a daily loading of 32.2 m^3/d (Table A6), approximately 381 kg of P would have been applied as of Fall 1981. The unsaturated soil volume beneath beds 2 and 3 was estimated at 3.5×10^9 grams (79.2 m x 30.5 m x 0.9 m = 2174 m^3; Bulk Density = 1.6 g/cm^3). Thus, the apparent P immobilization was estimated to equal approximately 109 ug/g soil. This value is well within the range of values presented previously by Sikora and Corey (1976).

A limited number of samples (two from each well) were analyzed for chemical oxygen demand (COD). Mean concentrations measured varied from 37 to 86 mg/L compared to 338 mg/L in the applied wastewater and 5 mg/L in the background groundwater at well 1-3 (Tables 8 and A14). These data suggested that significant attenuation of COD occurred.

The maximum concentration of fecal coliform bacteria measured at wells 13-3, 18 and 19 was 8 organisms/100 mL (Table A14). This maximum concentration was lower than that measured in the background wells (wells 3-1, 21, 3).

The groundwater quality degradation exhibited in the immediate vicinity of the beds appeared to be limited to the upper layer of the groundwater. For example, samples collected from nested wells at well location 13 exhibited decreasing levels of the measured parameters with increasing depth. Levels measured in the deepest wells (6.4 m deeper than the shallow well) approached background quality (Tables A12 - A14).

At well 12, approximately 32 m (105 ft) downgradient from the edge of Bed 3 (Figure 3), the concentration of various measured conservative parameters were lower than those measured at wells 13-3, 18 and 19 but still significantly higher ($\alpha = 0.05$) than background levels (Table A12). There are at least two possible explanations for these data. It may be that the effluent plume found in the immediate vicinity of the beds was dissipated somewhat, probably by dilution and dispersion within the groundwater. Another explanation is that samples withdrawn from well 12 may not have been from within the effluent plume but on its fringe.

The mean concentration of ammonia nitrogen measured at well 12 was only 0.72 mg-N/L, but still significantly higher than the mean level at well 1-3 of 0.21 mg-N/L (Table A13). The mean concentration of phosphorus was not significantly different from the background levels at well 1-3. The chemical oxygen demand (COD) measured in two samples from well 12 were 19 and 38 mg/l (Table A14). The COD concentrations were higher than the 5 mg/L or less determined in two samples from well 1-3, a background well. Fecal coliform bacteria were not detected in the groundwater samples extracted from well 12 (Table A14).

The groundwater quality data from well 12 revealed reductions in the elevated levels of potential pollutants measured in the groundwater near the

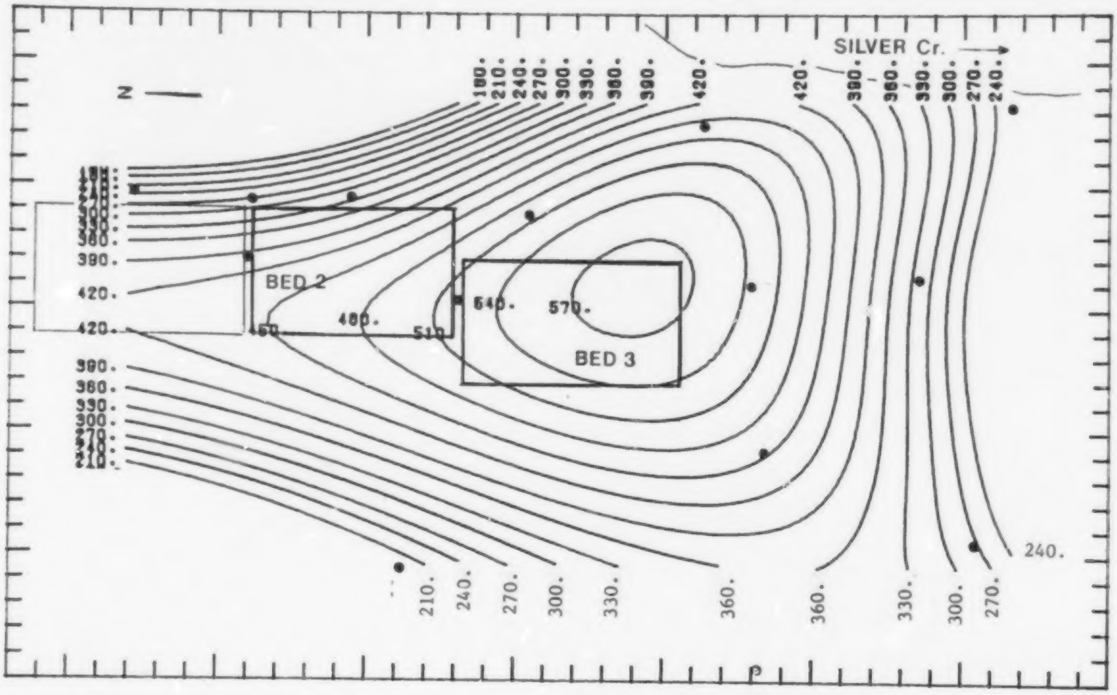

Figure A14. Computer Generated Plot of Total Dissolved Solids Levels on August 27, 1981 (Scale: 1 unit = 3.75 ft).

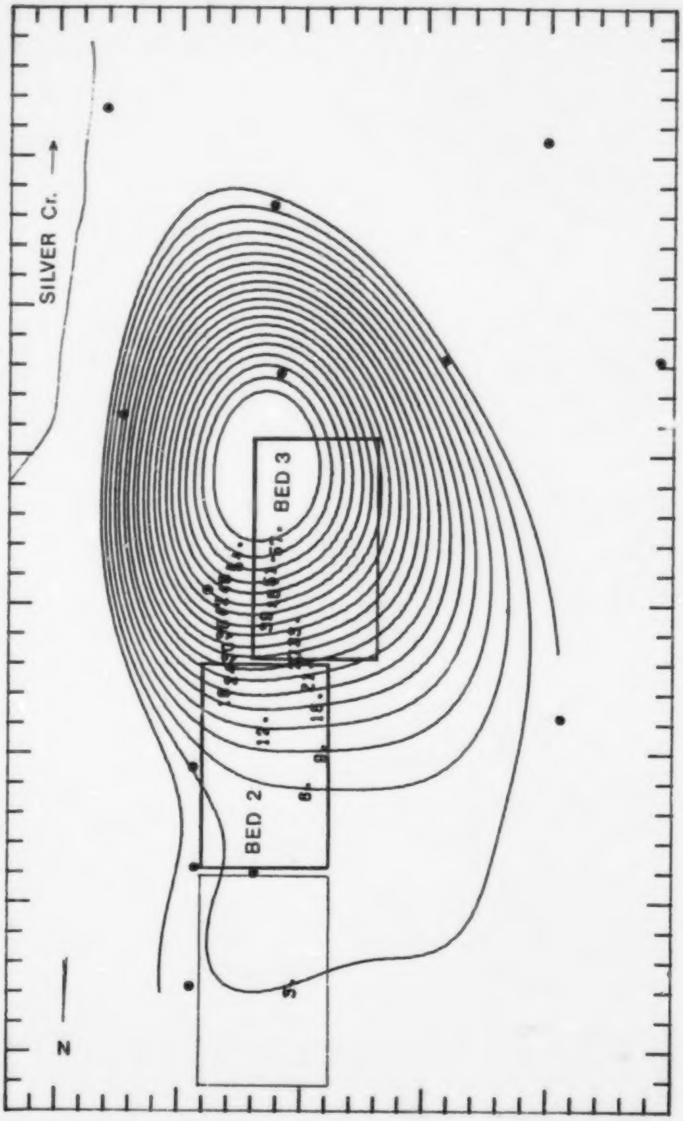
SILVER Cr.
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Figure A15. Computer Generated Plot of Ammonia Nitrogen Levels on August 27, 1981 (Scale: 1 unit = 3.75 ft).

beds (Table 8). These data suggest that pollutant attenuation through dilution and dispersion or removal and degradation may have been achieved within the saturated zone. The groundwater extracted from well 11, approximately 82.3 m downgradient and adjacent to Silver Creek, exhibited water quality essentially equal to that of the upgradient groundwater (Tables 8 and A12-A14).

Nitrogen Transformations --

The groundwater quality data collected in this study regarding ammonia nitrogen levels clearly demonstrated that anaerobic conditions were present under the wastewater absorption beds. As shown in Table 8, the mean ammonia concentrations in the groundwater increased from near zero at well 1-3 to over 40 mgN/L at wells 18 and 13-3. These data were consistent with the soil atmospheric data which revealed high levels of methane gas in the soil atmosphere under Bed 2 (Table 6).

Early post-startup monitoring of the absorption system (Fall, 1977) demonstrated higher concentrations of nitrate nitrogen at well 13-3. Figure A16 depicts the concentrations of nitrate and ammonia nitrogen measured over time since system startup in this well. Since wells 17-22 were not installed until 1979, well 13-3 was the only shallow well in the immediate vicinity of the beds. The figure shows NO_3 levels in the groundwater from well 13-3 increasing after system startup, however, nitrate levels started decreasing while ammonia nitrogen levels increased. This trend continued until nitrate levels stabilized at levels consistently below 5 mgN/L and ammonia nitrogen levels at levels above 30 mgN/L. In June of 1979, continuous ponding was noted in all three beds at Westboro (see following section on operation and maintenance). This corresponded to the time when ammonia levels were most rapidly rising in well 13-3 (Figure A16). Once the infiltrative surfaces of the absorption beds became continuously ponded, the area available for oxygen diffusion into the soil was greatly reduced. It was theorized that continuous ponding caused anaerobic conditions to develop under the beds at Westboro, resulting in the high ammonia nitrogen and low nitrate nitrogen levels measured in the underlying groundwater.

Surface Water Quality

Water quality monitoring in Silver Creek was conducted upstream and downstream of the wastewater absorption beds (Figure 3). Though various concentrations of potential pollutants were measured, levels upstream and downstream of the system were not significantly different (Table A16). This is not surprising since the minimum stream flow of Silver Creek is approximately 750 times greater than the wastewater flow (Carl C. Crane, 1976). Assuming complete mixing in the stream prior to the downstream sampling point, to raise the concentration of a pollutant 1 mg/L in the stream would require an input concentration of 750 mg/L.

Surface water samples were also collected from the intermittent flow in the drainage ditch located approximately 18 m (60 ft) south of Bed 3 (Table

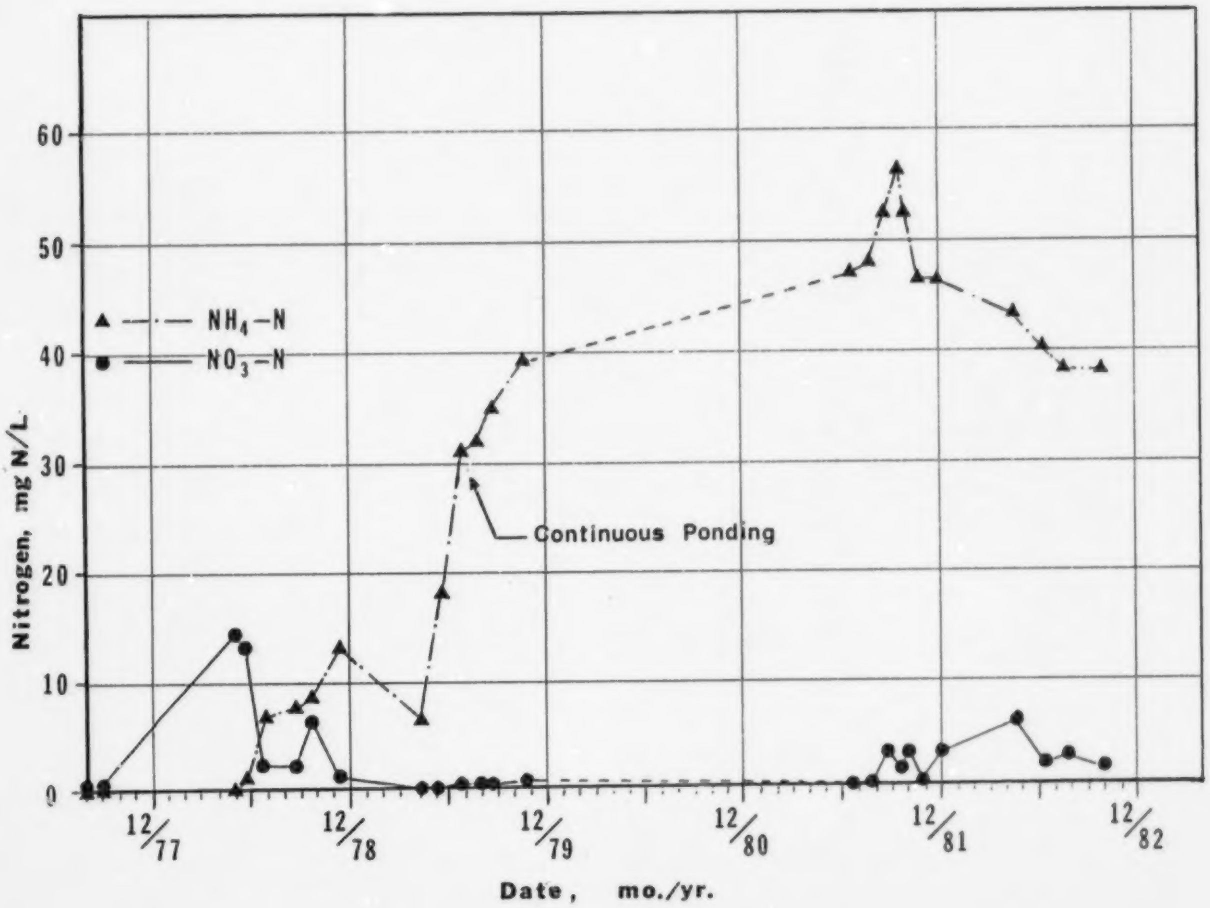

Figure A16. Ammonia and Nitrate Nitrogen Concentrations at Well 13-3 Versus Time.

Table A16. Surface Water Quality in the Vicinity of the Wastewater Absorption Beds.

Location	Statistic	TDS (mg/L)	Cl- (mg/L)	Cond. (μmhos/cm)	TKN (mg-N/L)	NH_4 (mg-N/L)	NO_3 (mg-N/L)	P (mg-P/L)	COD (mg/L)	F. Coli. (#/100 mL)
Silver Creek - Upstream	Mean	154	3.0	108	1.55	0.16	1.36	0.06	66.5	-
	S.D.	57.8	1.2	23	1.49	0.05	0.65	0.05	-	-
	Min.	55	2.0	85	0.7	<0.1	<0.1	0.02	33	88
	Max.	222	5.0	138	4.2	3.4	2.0	0.13	100	720
	n	6	8	6	5	7	8	5	2	5
Silver Creek - Downstream	Mean	169	2.3	108	0.59	0.50	1.50	0.05	43.5	-
	S.D.	43.0	0.7	25	0.29	0.80	0.70	0.03	-	-
	Min.	100	2	90	0.3	0.1	0.9	0.02	20	64
	Max.	215	4	144	3.8	2.0	2.0	0.08	67	6,100
	n	7	9	6	6	9	9	6	2	6
Drainage Ditch	Mean	350	28	440	5.6	5.3	7.6	0.03	23.5	-
	S.D.	55.6	9	39	1.9	1.9	1.2	0.03	-	-
	Min.	292	13	396	3.6	3.3	6.0	0.01	15	<1
	Max.	428	55	484	8.1	8.1	9.3	0.07	32	1,780
	n	5	5	5	5	5	5	4	2	5

A16). These data indicated higher concentrations of most parameters compared to those measured in Silver Creek. The ditch bottom was at a lower elevation than the bottom of the absorption beds and adjacent groundwater levels and groundwater flow patterns indicated flow toward the ditch. Percolating effluent form the absorption beds could have seeped into the ditch after soil treatment or dilution via the groundwater. Since this ditch collected runoff from nearby fields and the discharge from an interceptor drain, it was impossible to ascertain the impact, if any, due specifically to the absorption beds.

Operation and Maintenance

Some uncertainty surrounded the operation and maintenance characteristics of the wastewater absorption beds between start up in September, 1977 and the initiation of this study in June, 1981. The design concept was to have two beds in service at any time, annually rotating a third resting bed into service. In practice, this has not been the case. Due to a malfunction of one siphon, Bed 1 received all of the wastewater during the first year of operation (estimated to be 2.8 cm/d). After correcting this problem in Fall, 1978, Bed 1 was taken out of service and Beds 2 and 3 were put on line. Beds 2 and 3 have been used almost continuously since that time. Attempts to utilize Bed 1 have been unsuccessful as it becomes continuously ponded soon after putting it on line. This is probably due in large part to the soil conditions in the area of bed 1 which were identified as poorly suited to long term wastewater absorption (refer to discussions of site and soil characteristics).

Periodic malfunctions of the siphon dosing system have occurred since startup. Constant "dribbling" of the siphon feeding Bed 1 was noted within the first year of operation. Investigation revealed that a faulty siphon assembly was responsible for the problem. This was corrected during Spring, 1978. While Bed 1 was out of service, the two siphons discharging to Beds 2 and 3 should have automatically alternated discharges to the two beds. However, on several occasions during this study, the siphon dosing system was found to be malfunctioning. Wastewater would dribble out one or the other siphons, often the siphon supplying Bed 3. This condition would persist until air was pumped under the siphon bell. During Fall, 1983, the problem was corrected by cleaning and tightening all joints in the piping.

After discovering that the absorption beds were continually ponded, it was suspected that the beds were being adversely impacted by large amounts of subsurface water moving laterally downslope into the systems. To correct this an interceptor drain was designed and installed during Fall, 1980. A perforated 10-cm (4-in) diameter pipe was installed in a gravel filled trench. The trench was dug along the west edge of the beds to the drainage ditch running along the south side of Bed 3 (Figure 3). The drain pipe was laid with its invert at the north terminus set at an elevation of approximately 1500.5 ft (457 m). The pipe was laid with approximately 0.2% slope to the outlet point. Thus, the invert of the drain was roughly 3.2 ft (1.0 m) below the bottom of the absorption beds.

During the spring and fall seasons, the interceptor drain discharged a small amount of water. This was believed to be shallow, laterally-flowing subsurface water which occurred intermittently in response to snow melts and rainfall. Three grab samples of the discharge from the interceptor drain exhibited characteristics similar to that measured at well 1-3.